REPORT

Technical Assistance Sundarban

Strong and future proof flood defences

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1 Introduction

The Government of the Netherlands received a request from the Government of West Bengal (Department of Irrigation and Waterways) through the Netherlands Embassy in India, for support on flood risk management of the Sundarban. This request was favorably received by the Netherlands Government who took action and organized a Dutch expert team within the framework of the Dutch Disaster Risk Reduction (DRR) programme. A first mission took place over the period 16 – 28 April 2022. The DRR team mission consisted of four experts with varying expertise; dike engineering, delta morphology, integrated water resources management and nature-based solutions (NBS). The mission identified, among other things, that the current embankments in the Sundarban area provide insufficient protection and a lack of dike expertise is an urgent bottleneck to structurally improve the safety level of the area. A recommendation was included to support the technical team of the Government of West Bengal (Department of Irrigation and Waterways) with Dutch expertise in dike design to achieve a more structural approach.

October 2022, dike specialist Sander Post went on a working visit to India for technical support regarding dike design. During his visit, many recommendations on dike design were discussed with the Indian counterparts on-site. Several additional technical questions are currently being further elaborated.

This report briefly summarizes the main recommendations on technical dike design. Three levels are distinguished; 1. General recommendations for designing dikes the Sundarban area, 2. recommendations focused on detailed dike design (cross section level), 3. recommendation for dike design at specific sites (sites which were visited during the field trip). The report concludes with recommendations for further technical support to the IRWM.

2 Dikes and embankments in the Sundarbans

2.1 Current situation

For flood resilience, the Sundarban area relies on embankments and sea dikes. Nowadays the total length of embankments and flood defence structures in the Sundarban is around 1800 km. The state of some of these structures is poor and their condition became even worse after cyclone Yaas. Dike designs in earlier years were below standard, for example with steep slopes and without any filter layer underneath the concrete slab or brick block protections, resulting in failure of the outer revetment. Outdated manuals are in use without references to good international practices. Also, proper design was hampered by considerations of limiting cost and short cuts were allowed during execution of the works due to condoned practical on-site construction and implementation constraints.

In March 2021, new recommendations were laid down in IWD (2021). More robust dike constructions were proposed, and geo-synthetic textile filter was introduced to be placed underneath the concrete – brick block protection. UC Bullah are recommended as toe protection. Porcupine spurs are recommended to be placed in front of the dike and where possible and provided a required volume of sediment accretion has occurred, the planting of mangroves. Where extra severe conditions exist, tetrapods are used for dike protection or protection of the toe.

The recommendations have been adopted in the new dike designs and are being implemented in the field. When comparing the recommendations with good international practice on sea dike design and construction some further study and knowledge exchange could be considered in view of still unsolved failure mechanisms which can be observed on site - notably still poor filter and toe protection design and on-site execution. With investment of US$ 1 million for one kilometer of sea dike it is worthwhile to reconsider design and execution practices to avoid lost investments when the rehabilitated and new dikes will fail again with the next serious cyclone.

The risk of flooding from dike breaches along the river and coastal stretches of the Sundarban is significant, also on an annual basis. Efforts to strengthen the area's line of defense need to go in parallel with ongoing activities in building resilience for the areas and its people. During the last typhoon, at 700 locations the diking system got breached and areas got flooded. Localized flooding can be disruptive, while the more extreme events could also cause fatalities. The challenge for the Sundarban is to be a safe place for its people. Coastal resilience is about being prepared when the next event occurs. Besides structural measures (e.g. building dikes), non-structural measures are a very important part of the way forward. Sustainable planning, zoning of flood prone areas and emergency response activities and procedures will lift the area's resilience.

The Sundarban embankments and sea dikes have, especially in recent years, suffered heavily from storm surges caused by cyclones and high river floods. Observations from the site visit can be summarized as follows. There is an absolute need to invest in strong, sustainable, and future proof embankments. Moreover, there are opportunities to include mangroves as a vegetated foreshore, which can contribute to flood safety and have potential in locations of dike realignment. Realignment might be needed at eroding riverbanks. Lastly, it is important to have a set-up for planning and zoning, strengthening the policy, governance and enforcement when living with water.

2.2 Observations from field trips

During field trips and different meetings with officers from the Department of Irrigation and Waterways better insight was gained in the challenges the Sundarban is facing. Besides the breach locations and the pace of the subsequent reconstruction works, also the size and complexity of building, (re)constructing embankments and levees became clear. It is important to take on board all lessons learnt while moving forward. Another insight out of the fieldtrip and the numerous conversations is the need for prioritization. Where to start first? A programmatic risk-based approach to this is crucial, by prioritizing the realignment and reconstruction of the dike improvement works.

The most relevant observations from the site visits, the meetings with the officials from the Department of Irrigation and Waterways and our understanding of the report of the IWD (2021) are summarized below.

1. *An absolute need to invest in strong, sustainable and future proof embankments.* The required level of protection, the alignment of the embankments, sea dikes and its function are important aspects to be considered per stretch. Based on a cost benefit assessment, value of protected lands should be balanced with the investments in flood protection works.
2. *Opportunities to include mangroves as a vegetated foreshore, which can contribute to flood safety and have potential in locations of dike realignment.* Nature-Based Solutions should be integrated in the design of flood protection structures. This should not be confused with allowing trees to grow in or close to the slopes of the embankments. It is recommended to keep at least 5-10 m out of the dike toe free of trees. Nature-Based Solutions, e.g. a foreshore vegetated with mangrove forest can in a sustainable manner, reduce impact of wave action and therefore contribute to the reduction of crest level and footprint of the embankments.
3. *Realignment might be needed at eroding riverbanks.* To counter the impact of erosion and reduced tidal amplification, the most sustainable way forward seems to be the realignment of some of the embankments. The vulnerability mapping on potential areas, susceptible to strong erosion in the future, will outline these sites. Temporary measures such as porcupines will slow down the process, but more strategic long-term measures are necessary to safeguard the people and their lands. Realignment is a complex process. All stakeholders need to be consulted and included in the process to arrive at a sustainable solution.
4. *Development of a pathway for planning and zoning, strengthening the policy, governance and enforcement when living with water.* Operation and maintenance are crucial parts in the management of assets (e.g., embankments, outlet sluices, gates). A plan for monitoring and control needs to be available and executed, including frequent surveying and visual inspections of the embankment, the sea dikes and their foreshore and hinterlands. This will enable the Department of Irrigation and Waterways to quickly respond in case of repairs or emergencies and at the same time insight will be gained into the structural life of the asset, allowing the teams to proactively plan ahead.

3 Recommendations design process

The 1800 kilometers of embankments, sea dikes and structures suffered over 700 breaches in the most recent cyclone Amphan. Emergency response and repair activities have promptly been carried out. The key question is where to pro-actively start reinforcing the flood protection structures. It is recommended to prepare a strategy and implementation plan to bring all flood defence structures up to the required level of protection. This also needs to fit in with the wider strategy for the Sundarban, supporting the further development into a safe and sustainable environment for the area and its people. In order to organize and to prioritize the embankment and sea dike reconstruction work a close understanding is required on the hazards and the risks for the area. The process can be broken down in five steps.

1. Based on vulnerability mapping for the area, those flood protection structures most impacted by storm surges and cyclones can be identified. River and coastal stretches prone to erosion are relevant too. This mapping will highlight areas, stretches most at risk.
2. From a structural perspective for the embankments and sea dikes an inventory is required on their current condition. Which embankment and structures are up to standard, and which require maintenance or repair urgently? This is a massive catching up exercise for the Department of Irrigation and Waterways to do but is crucial in understanding the sort and number of weak spots.
3. Not all areas of the Sundarban require the same level of protection. Villages, people, livelihoods, farmlands need to be protected. Other areas, for example nature reserves or aquaculture fields are of a different order because impact of flooding is less. For example, do 500 meter no building zones require flood protection? A map outlining the differences will further guide the process of prioritization of high-risk areas.
4. Combining the cyclone hazards, the status and quality of the existing flood defence structures will point into the direction of weakest spots within the 1800 kilometres of embankments and sea dikes. Knowing the high-risk areas, the valuable and important sites will further assist in the categorization and prioritization of flood protection works.
5. All together in a strategic roadmap, presented over time for the next decade, will combine and present short-term fixes and long-term perspective for making the Sundarban a cyclone safe place to be. This roadmap is not cast in stone of course, it should periodically be updated based on new insights and understanding in the area.

The design process of an embankment, sea dike or protection structures as per the International Levee handbook is presented in Appendix 1. The design of an embankment or sea dike is a multidisciplinary exercise in which hydraulic, geomorphological, and geotechnical aspects are considered and balanced. This is not a stand-alone flowchart but should be read together with the other flowcharts in the manual. Nevertheless, it provides overview, order of sequence and key points of decision making by the designers to arrive at the preferred design solution.

The collection of data is crucial to understand the area, the river, other water courses and the embankment and to make informed decisions on design and layout moving forward. The process of data collection can be divided across different design phases of the project, building upon lessons learnt and gained insights. Examples of relevant items to be collected are morphological and hydraulic data on behaviour of rivers and coastlines (incl. scour), soil conditions, geotechnical data of existing embankments and sea dikes, geometry of flood defence structures including foreshore and hinterland survey/digital terrain models and for example current land use and future development plans. Table 9.2 from the International Levee Handbook provides an overview of a logical data process for each design stage.

Erosion threatens the structural integrity of embankments and dikes in the Sundarban. Many of these embankments are located close to the river and the erosion process gradually scrapes away the foreshore, essential for the overall stability of the embankment. Fixating these foreshores by placing porcupines provides a solution in the short term. The more sustainable solution would be to realign these stretches of embankment inland, ensuring sufficient foreshore, sufficient buffer area preventing instability of the

structures. A vulnerability assessment will highlight these areas, a balanced approach needs to be found between realigning and interest of the people and their livelihoods on the inside. This requires a tailor-made approach and should be dealt with on a plot-by-plot level.

The basic design process, from the flowchart in Appendix 1, can be summarized in the following steps, referring to the different chapters from the International Levee Handbook:

1. What are the governing hydraulic boundary conditions (water levels, waves)?
2. Determination of flood protection standard. What is the alignment, crest level?
3. Initial sketch of preferred geometry, slope, berm, foreshore, hinterland, in line with chapter 9.5.
4. Check on geotechnical dike stability, macro (slope) stability, micro stability, piping in line with chapter 9.7 and 9.10.
5. Design of revetments (nature-based solutions, grass, concrete/rock), chapter 9.6.
6. Combination, variation with local environmental conditions.

In the geotechnical and structural design of the embankments the identification and selection of fill materials is important. These (earthworks) materials need to be selected, tested from potential borrow sources. Best structural performance, cost and environmental aspects need to be balanced. Clay material (and to a lesser extend the layer of topsoil supporting growth of well rooted grass desk) need to be the erosion-resistant layer (TAW, 1996). Therefore sand content (<40%), organic material (<5%) and salt content (<4%) should be within limits and minimal threshold levels for its liquid limit (>45), plasticity index (>18) and water content (>0,6) are required because of its workability. Testing needs to be done at regular intervals, making sure that homogeneous quality of clay layer is achieved. The clay material should be free from debris, wood, logs, stumps, roots etc. and of extreme coloring or smell. The technical requirements of the core material of the embankments can be less strict. A more sandy (>40%), clayey gravel type of material suffice, excluding peat, materials from swamps, marshes and bogs. For reason of settlement and consolidation the organic content should be limited and also the core material should be free from debris, wood, logs, stumps, roots etc.

The implementation of Nature-Based Solutions (NBS) has a large potential for the Sundarban delta and should be an important design topic. NBS is an umbrella term and includes approaches that involve working with nature to address challenges (e.g flood protection). The main NBS for this area should focus on trapping sediment within the delta in the right places. Sediment trapping can counterbalance the impact of sea-level rise and subsidence by creating a gradual transition from land to sea with a protective mangrove greenbelt, dampening waves and peak flow velocities along riverbanks. See the Figure below for four common types of NBS to trap sediment. During the field visit the site Rupmari was visited, where a double dike system proves this concept work effective. It is suggested to design and implement other pilot projects with NBS at larger scale on suitable locations.

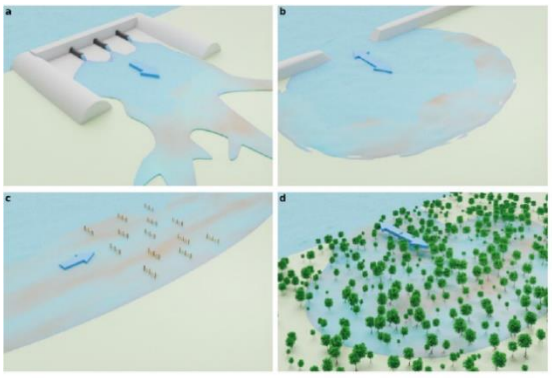


Figure 1: Illustrations of NBS to trap sediment (Cox et al., 2022): (a) River sediment diversion, (b) tidal flooding, (c) sedimentation structures, and (d) sediment trapping vegetation. Arrows indicate flow direction.

NBS principles often take some time to reach maturity, while the need to improve flood protection is very urgent. Therefore, often a combination of NBS (mid-term) and dike reinforcement (urgent/now) proves to be the best way forward, both technically and financially when investing in future proof embankments.

Another NBS which could be explored more extensively is to include mangroves as a vegetated foreshore, which can contribute to flood safety and have potential in locations of dike realignment. However, mangroves may not grow through revetments of embankments.

Special attention should be paid to counteract the erosion process of foreshores. Temporary measures may slow down the erosion process, but more strategic long-term measures are necessary to safeguard the people and their lands. An example of temporary measure are porcupines, which are tripod shaped structures made of open concrete or wooden poles to slow down flow velocity and enhance sedimentation. Another temporary measure are nourishments of sand in front of sea dikes. This can be a very effective measure if repeated in time.

4 Technical recommendations dike design

The following section provides recommendations for the technical design of dikes. The recommendations are more technical and more specific than the recommendations in previous section. For readability, a distinction has been made between different dike components. The last section includes a recommendation for maintenance.

4.1 Geometry and dimensions

1. Strong eroding riverbanks and foreshores near an embankment needs to be protected urgently. However, structural erosion resulting from a sediment deficit requires very strong embankments (including foreshores and hinterland) and may be better mitigated by managed retreat. To counter the impact of erosion at riverbanks effectively, realignment of embankments in landward direction is probably the most sustainable solution to provide flood and river protection. Realignment is a complex process (both technically as politically). This report further focuses only on technical advice
2. The acceptable rate of overtopping determines the dike footprint/dimensions (crest height, slopes, berm, foreshore). Therefore, it is crucial to determine the acceptable rate of wave overtopping first. This will be site specific. To determine the acceptable rate of overtopping the Wave Overtopping Manual (www.overtopping-manual.com) can be used. A rate in the order of 10 l/s/m corresponds to the most ideal situation in combination with an inner slope of 1:2 (or flatter) and a grass toplayer. Due to the local constraints a higher wave overtopping rate can be considered. However, the consequence is that the chance of dike failure will increase.
3. Many locations that were visited show steep embankment slopes ranging from 1:1 to 1:2. Most ideal are slopes in the order of 1:3 or flatter. Therefore, a thorough check on stability is required for every location, including transitions. It is recommended to flatten the slopes and toe widen the footprint. To improve the stability the construction of earthen berms could be considered. The increased footprint area of the embankment should be found in the landwards direction.
4. A key failure mechanism in the Sundarbans is wave overtopping. To reduce wave overtopping the wave run-up height should be extended. Flattening the outer dike slope is the most logical reinforcement measure. The increased footprint area of the embankment should be preferably found in the landwards direction.
5. Excavations on the landward side of the dike may pose a stability issue as it enhances seepage. Activities such as clay mining or aqua farming involve excavations, as was often witnessed in the field. When located close to the dike it may trigger seepage and subsequent failing of the dike. It is recommended to prevent any excavations within 10 meter to the toe of the dike and relocate aquaculture activities to locations where it is outside the zone of influence of the dike. By adopting an inner slope of minimum 1:4 the impact of seepage can be minimized, for instance for locations where aquaculture cannot be shifted to other locations.

4.2 Construction materials

4.2.1 Embankments

6. The top layer material of the dike that were visited does not seem to be well compacted and does not show erosion resistance. A check on micro-stability and its toe structure is important to ensure structural stability of these earthen embankments.
7. The material characteristics and the grade of compaction of core and slope materials is crucial for the strength and stability for the embankments and sea dikes. Moisture content, compaction, workability are crucial aspects during construction. Preventing large settlement and uncontrolled consolidation, therefore it is crucial to build well compacted, gradually layered/build dikes.
8. Grass top layer (or similar) -well maintained and rooted- at slopes and crest will prevent the risk of erosion during overtopping significantly. The current slopes often are unprotected (bare clay with

cracks) and could therefore only deal with marginal quantities of overtopping water. In order to improve the erosion protection of the dike top layer, it is recommended to include a 20cm sandy layer of topsoil plus deeply rooted, salt tolerant grass.

9. Where wave action is negligible, grass turfing is a good option for slope protection, even at the outer slope of the embankment above the still water line.

4.2.2 Pattern block placed revetments

10. Brick revetments do not have a large lifespan. Especially at sites with large wave impact and saline conditions it is strongly recommended to use other block placed revetments (for example concrete blocks or rock/riprap revetments).
11. For sites where high waves can occur roughened blocks can be used to reduce wave run up and to reduce the required crest height. It is very important the roughness elements are fully integrated in the revetment and not only be placed on top of the revetment.
12. The toe structure fixates pattern block placed revetments on slopes and should be stable to counter the impact of erosion, scour, de-rooted mangrove trees and settlement of the structure. If a toe structure fails, the whole block placed revetment is likely to fail.
13. The end of the toe structure should be flexible, being able to adjust to changing foreshores. Examples of tetrapods have been seen. Interface between concrete and sand needs to be softened. Rocks on a filter structure can act as a fallon apron providing stability to the slopes, when scour, close to the toe occurs. Monitoring is needed.

4.2.3 Floodwall

14. If a vertical floodwall is located on the crest of a dike. The structural stability and integrity of the floodwall is crucial. The impact of dynamic loading and settlement needs to be considered in the design of the vertical structure. Settlement and consolidation of the earthen core needs to be limited to avoid gaps, resulting in erosion.

4.3 Protection of foreshores

4.3.1 River training or realigning works

15. For the use of (small) river training good understanding of the hydrodynamic and morphological processes is required. Hydrodynamic and morphological models can predict these processes and can be used to test the effectiveness of river training works. If there is a lack of data, learning by doing and evaluating can be considered. However, river training can be a solution to counteract erosion at specific site but often the situation at another site will be worse.
16. In those areas where the embankments are aligned close to deep river channels, realignment is the sustainable way forward. In those areas where this cannot be achieved in the short term (next couple of years), intermediate measures should be implemented to prevent the foreshore from eroding. NBS can stimulate growth of foreshores. Porcupine structures are a proven ‘intermediate’ solution.
17. Strong eroding riverbanks and foreshores near an embankment need to be protected urgently or the embankment should be shift in landwards direction. A fascine mattress is a proven concept to protect underwater and toe slopes, it is for example successfully been used in Bangladesh. It is recommended to start a pilot project in order to gain experience with the type of measures. The use of an alternative of boulder stones can be examined during this pilot project.
18. Boulder stones (riprap) in combination with geotextiles/fascine mattresses often are used as part of bed protection and slope protection. If boulder stones are not available, an equivalent alternative should be found.

4.3.2 Nourishments

19. For the coastline area nourishments can be a sustainable solution Sediment nourished at one location will locally lead to accretion of the beach and foreshore. This accreting beach / foreshore will migrate

downdrift, supplying the coastlines northward of the suppletion. Nourishments need to be carried out repeatedly (where the interval depends on the volume of sediment supplied, e.g. yearly or once in a few years).

20. Nourishments are not a replacement of embankments, but a way to protect the embankments. They thereby lead to lower maintenance and repair costs, also positively impacting on sea dike (re)construction cost.

4.3.3 Operation and maintenance

21. Operation and maintenance are crucial in the management of embankments. A site-specific plan for monitoring and maintenance needs to be available and executed. This includes frequent surveying and visual inspections of the river embankment, the sea dikes and their foreshore and hinterlands. Specific issues to be checked before storm seasons and after (and preferably, if safe, during) each major storm are:
    a. Condition of the dike revetment layers. Are all layers intact; is a filter/geotextile exposed? If so, immediate repair is required.
    b. Is there visible erosion on the dike profile? if so, immediate repair is required.
    c. Are the slides that need to be repaired?
    d. Is the dike profile free of objects (e.g. debris/trees)?

    Deep river channels near the embankment profile should be monitored on frequent basis (e.g. yearly).

5 Site specific recommendations dike design

The field visit took place on the 12th and 18th of October 2022, together with officials from the Department of Irrigation and Waterways. During the field visit 9 specific sites were visited. This paragraph provides an overview of the most relevant observations and recommendations for each site. The recommendations were arrived after onsite discussion with the officials of the Department of Irrigation and Waterways and often with local residents. However, many of the following advises are based on little data and locally available resources and therefore some advises do not correspond with the most optimal solution.

5.1.1 Site 1 Rupmari







Observations at this site:

- Pilot project in progress -> great to see;
- Sort of double dike system (new dike is realigned landwards);
- Area traps sediment, which is used to construct the dike (Nature-Based Solution);
- Very stiff clay (erosion resistant), but with cracks, exposed directly to sunlight;
- No sandy top layer or grass cover present;
- Very steep inner slope, especially near fish pond stability issues can be expected.

Recommendations:

- Nature based solution (sediment trapping) is working!
- Inner slope needs to be flattened, probably a 1:2 slope is already stable of a combination of 1:1 and 1:3 slope. A stability check is required. Most ideal solution is to relocate the fishpond and to flatten the slope together.



- Vegetation is needed to prevent clay cracks and to make the dike much more erosion resistant, due to the mild wave climate at this site a grass cover will be sufficient.
- An additional geotube or wooden dam in longitudinal direction probably accelerate the growth of the foreshore.

5.1.2 Site 2 Dayapur







Observations at this site:

- Interesting point (starting point of two river branches - confluence);
- Eroding foreshore;
- Very steep slopes, river pond at the landside
- Probably also a very deep river channel is present just before the dike (please check)
- No vegetation is present at the embankment

Recommendations:

- Start with bathymetry survey
- Filling scour holes and flatten underwater slopes if necessary, then protect and stabilize the toe slopes (fascine mattress)
- Try to predict morphological processes at this point, where will accretion/erosion occur. A morphological model can help to gain insights.
    - Maybe one river channel will silt up completely
- The erosion process of the foreshore needs to be stopped immediately
    - Use of fascine matrass on a stable slope (maybe nourishment is necessary)
    - Make sure the ballast material is not eroded due to high flow velocities in the river, so heavy weight material is likely to be needed.
- Consider the use of porcupines at foreshore
- Most optimal solution -> relocate the main embankment landwards (double dike system) like Rupmari.
- River training works can be examined at this site (study is required)
- Avoid steep slopes (1:1)

5.1.3 Site 3 Kalidaspur







Observations at this site:

- Eroding foreshore (very small);
- Very steep slopes (1:1), river pond at the landside
    - Stability problems are likely
- Probably a very deep river channel and scour holes are present just before the dike (please check)
- No vegetation is present at the embankment

Recommendations:

- Most optimal solution -> relocate main embankment land inwards, due to a lack of available land this will be difficult,
- Stop eroding process of the foreshore
    - Soil testing at the river side
    - Scour hole filling, flatten slope is necessary
    - Bed protection – fascine mat
    - Try to use small river training works (groynes);
        - Small dams perpendicular to the dike (to train the river)
- Vegetation, revetment on earthen embankments is needed.
    - top layer of 30cm (sandy clay), maybe in combination with a geogrid
    - Brick blocks revetment if waves occur >0,5m.
- Relocate or fill fish ponds next to dike for stability reasons

5.1.4 Site 4 Kumirmari






Observations at this site:

- Failure of the brick block layer;
- A very small foreshore;
- Wave climate is considerable
- Good vegetation on inner slope.

Recommendations:

- If possible, try to stimulate growth of the foreshore;
- Proper compaction of the earthen embankment is needed. Horizontal soil reinforcement can be used;
- New brick block revetment on stable slope (1:5 if enough space is available);
- Do not forget a filter layer 100mm with geotextile below it(crushed brick blocks for example) below the revetment;
- Maintenance of the new revetment layer is needed; fill gaps larger than 20mm;
- Stable toe structure is required (concrete blocks);
- Consider to use a revetment with roughness elements to reduce wave overtopping and to reduce the required crest height.

5.1.5 Site 5 Saugheri





Observations at this site:

- Sea-faced embankment
- Urgent action is required, embankment is too steep and too low
- Geotextile is subject to direct sunlight (short lifespan)
- Eroding sandy foreshore
- High waves can occur at this side

Recommendations:

- Most optimal solution; beach nourishment and shifting the dike in landwards direction
- This side is suitable for a pilot project;
    - Using a concrete block mat (steel cables needed?)
    - A filter with geotextile is recommended



- Determine the acceptable overtopping rate and then determine the dike dimensions
    - For example: angles of slope, berm and crest height
    - A mild slope (1:5 or 1:6) slope is recommended
- A strong toe structure is required!
- Creating sediment traps to restore the beach (NBS)
    - T-shaped dams, Longitudinal and perpendicular dams/ geotubes, for stability reasons use three geotubes ->

5.1.6 Site 6 Bankimnager





Observations at this site:

- Urgent action is required, embankment is too steep and too low
- Very committed and concerned residents
- Geotextile is subject to direct sunlight (short lifespan)
- Proposed design with reinforced soil with a 1:1 slope seems too steep
    - Resulting in too much wave overtopping
- Doubtful whether a hard revetment is cost-effective here
- Very small foreshore

Recommendations:

- Most preferable option – shifting the main dike landwards
    - Most sustainable option (NBS)
    - Creating a sediment trap between old dike and new dike
- Consider a milder (less steep) slope (1:3?) in combination with an outer berm
    - More stable and a lower crest height is needed
- Regarding geotextile; try to prevent exposure to sun
- Existing foreshore needs to be protected
    - Explore the use of fascine matrass and porcupines here after a bathymetry survey has been carried out.

5.1.7 Site 7 Patibuniya



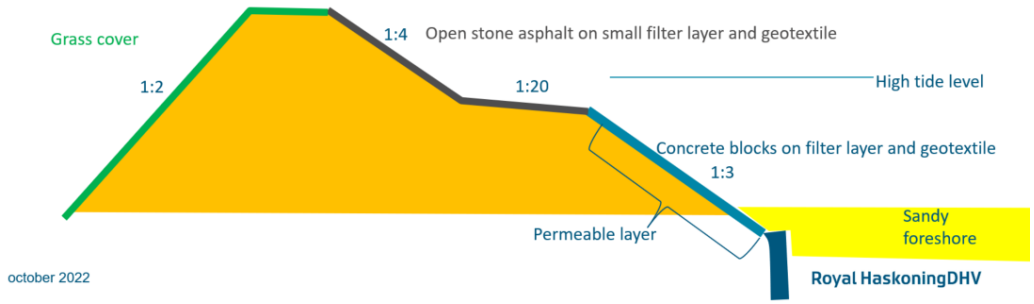


Observations at this site:

- Failure of the brick block layer
- Sandy foreshore is present
- the bricks may have been damaged by the saline environment
- Well vegetated inner slope

Recommendations:

- This site seems suitable for applying asphalt;
- Investigate of the foreshore is stable and if NBS can be (a part) of the solution here:
  - Sand/silt trap?
- Robust toe protection is required;
- Overpressures (lift forces) need to be avoided; therefore, the dike needs to be permeable to some extent;
- Proposed design:



5.1.8 Site 8 Frazerganj





Observations at this site:

- Revetment of large concrete plates (without roughness);
  - Overall condition good, small gaps and small damage of concrete elements:
    - Although erosion beneath the concrete may have taken place (not visible);
    - Eroding beach in front of revetment.
- Single tetrapods armour layer before the revetment at the beach;
- Small wave wall is present at dike crest (too low);
- Alarming settlement of toe structure:
  - It is believed that due to the heavy weight of the tetrapods the toe structure is subject to settlement.

Recommendations:

- Settlement of toe structure needs to be tackled urgently!
  - Interface between concrete and sand needs to be softened.
- Fill large gaps between concrete elements and repair cracks (maintenance)
- Determine the acceptable overtopping rate, then calculate the design crest height (with wave wall)
  - Use formulas of the Overtopping Manual
- If constructing wave wall:
  - A new wall (concrete) can be placed next to existing wall
  - Check the local stability
    - Rule of thumb for stability:
    - Construct 2/3 of the wall below ground surface and 1/3 above
- Consider beach nourishments (soft measure and NBS) to create more beach. It probably doesn't stop the erosion but reduce incoming waves. Occasionally beach nourishment must be repeated in time.

5.1.9 Site 9 Brajaballavpur






Observations at this site:

- Failure of the brick block layer
- Overall; a small foreshore is present, but eroding quickly
- The brick revetment layer may have been damaged by the saline environment
- Fish ponds at landside
- Urgent action is required, embankment is too steep and too low
- Geotextile is subject to direct sunlight (short lifespan)
- Stability of current toe structure is doubtful

Recommendations:

- Most optimal solution: Shift the dike landwards direction
- Outer slope of 1:5 or add a berm for more steep slopes
- Use concrete blocks instead of bricks for revetment layer
- Protect the current foreshore by using fascine mattress
- Plant mangrove trees (NBS)
- Stabilize the current toe structure (add weight at seaside)
- Consider roughening the upper part of the outer slope

5.1.10 Additional examples (discussed during field trip)

Fascine Matrasses

Fascine mattresses are large mats specifically designed to protect the shorelines of rivers and estuaries against the erosive effect of running water. They have been used for over 100 years to protect soils and banks against erosion by water. The mattresses consist of geotextile and bundles of brushwood. Very effective method to stabilize toe slopes.

Float the mattress to the site, use ballast (boulders stones are common) for sinking.

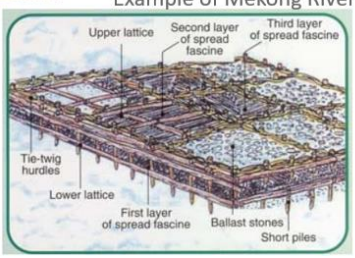






Also used in Bangladesh

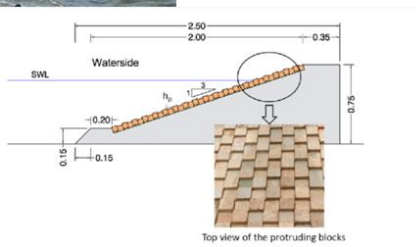
Example of Mekong River



Use of roughness elements

- Effective method in wave run up zone to reduce wave run up (wave damping)
  - Reducing crest heights and dike width
- Not effective below storm water levels





Salt marsh works in the Netherlands

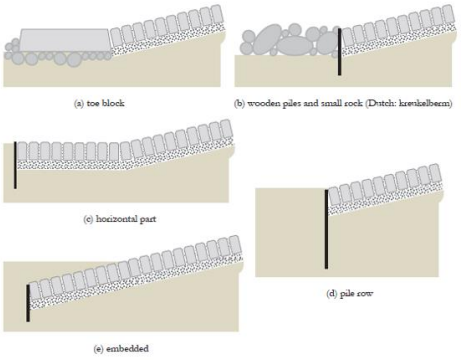
- Small dams in foreshore consisting of wooden piles and brushwood
- Effective method to stimulate growth of existing foreshores
- Not effective without any foreshore



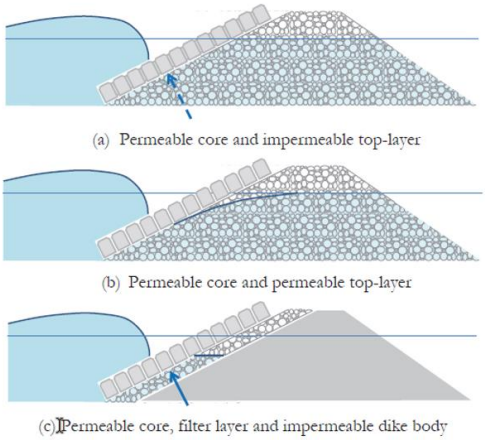


Toe stability

A dike toe needs maintenance for example: adding more ballast material on frequent basis



Failure of revetment due to uplift force



6 Recommendations for further technical assistance

The task for IWRM to strengthen the levees in the area is enormous. The team's determination to tackle this operation successfully is admirable. The DDR mission report, along with this report, provides an initial guidance to move forward. The recommendations for further technical assistance are listed below, mainly along the the different steps, identified in chapter 3 of this report.

1. Based on vulnerability mapping for the area, those flood protection structures most impacted by storm surges and cyclones must be identified. River and coastal stretches prone to erosion are relevant too. This mapping will highlight areas, stretches most at risk. Further technical assistance and longer-term support will help the IRWM design team in their technical challenges, planning and prioritizing efforts and means.

2. Assistance with hydrodynanic and morphological forecasting. The delta area is very dynamic, predicting erosion and sedimentation zones helps to prioritize dike reinforcement projects. A hydrodynamic model also helps to derive appropriate hydraulic boundary conditions for each site to improve the dike design. In the Netherlands we have extensive experience in using models to derive representative design loads.

3. From a structural perspective for the embankments and sea dikes an inventory is required on their current condition. Which embankment and structures are up to standard, and which require maintenance or repair urgently? This is a massive catching up exercise for the Department of Irrigation and Waterways to do but is crucial in understanding the sort and number of weak spots.

4. Not all areas of the Sundarban require the same level of protection. Villages, people, livelihoods, farmlands need to be protected. Other areas, for example nature reserves or aquaculture fields are of a different order because impact of flooding is less. For example, do 500 meter no building zones require flood protection? A map outlining the differences will further guide the process of prioritization of high-risk areas.

5. Combining the cyclone hazards, the status and quality of the existing flood defence structures will point into the direction of weakest spots within the 1800 kilometres of embankments and sea dikes. Knowing the high-risk areas, the valuable and important sites will further assist in the categorization and prioritization of flood protection works. Working together with a small Dutch team to design a specific dyke project from start to finish. Pilot projects could also be used to learn what works for the area, including Nature Based Solutions. In this way the team from IRWM will be introduced to all design steps in the Dutch approach.

6. Help to set up a proper maintenance and monitoring plan. Maintenance is crucial to keep dikes as robust as possible and to extend the lifetime of construction materials.

7. All together in a strategic roadmap, presented over time for the next decade, will combine and present short-term fixes and long-term perspective for making the Sundarban a cyclone safe place to be. This roadmap is not cast in stone of course, it should periodically be updated based on new insights and understanding in the area. In parallel this roadmap will allow the IRWM and the Dutch experts to discuss and set-up training and exchange visits to the Netherlands, Bangladesh and elsewhere. Consideration could be given to having a delegation from IRWM visit a number of dike strengthening projects in the Netherlands. Important here is to visit projects in preparation, projects in realization phase and completed projects.

Appendix 1 Levee Design Process

From International Levee Handbook:

