Case Study
Dyke Design, Construction and Maintenance
Lessons learned in Kien Giang Province Vietnam
Foreword

Rising sea levels due to climate change has caused erosion to become a serious problem in coastal areas around the world. Coastal erosion is widespread in Vietnam and to respond to this problem, the Government of Vietnam has introduced a dyke reinforcement program (Decision 667 by the Prime Minister - mangrove protection and sea dyke reinforcement).

In Kien Giang Province 50% of the coastline is eroding, in some areas at a rate of 50m per year. This poses a severe problem for the people living in coastal areas. The province has requested assistance to design an effective coastal protection system for its 205 km of coastline.

Dyke Design, Construction and Maintainance are all components of the overall integrated coastal management plan developed by the province. This document was prepared by Internationally recognised engineers who are highly specialized in flood control dykes and with a long term standing cooperation in Kien Giang province.

This document is prepared as a case study that shares the lessons learned by the Kien Giang Peoples Committee, particularly the Department of Agriculture and Rural Development (DARD), Department of Dyke Protection with other Provinces, Donors and Organisations responsible for the planning and implementation of dyke systems in Vietnam.

This document aims to:

- provide technical assistance!
- convince donors of the necessity to help the Province!
- help GIZ and Australian AID to assess the situation in five coastal provinces and to optimize their contributions and inputs!
- give non-scientific Vietnamese officials and representative some valuable guidelines!
- be used as a first step by those seeking technical information!

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Introduction

This case study describes the current situation along the coastline of Kien Giang province. The document is intended to assist decision makers and stakeholders in Kien Giang Province to assess the safety of the areas affected by coastal erosion or in need of dyke protection. We also assess the quality of design and construction of sea dykes as well as their maintenance and repair.

It is not the objective of this document to be used as a design manual. For this purpose, reference is made to the national and international standards and recommendations in the field of dyke design and dyke construction. However, the following statements are based on international standards and reflecting the state of the art.

1. General Aspects

Dykes are the most important flood protection structure in southern Vietnam (Figure 1). Dykes protect people, housing, infrastructure and agricultural areas such as rice fields and shrimp farms. Therefore, proper planning, design, construction and maintenance of these structures is of high importance for Vietnamese society, the economic benefit of the affected regions and the safety of all concerned individuals.

Dyke design, construction, repair and maintenance have to be carried out in such a way that safety is guaranteed, costs are minimized, ecological and environmental aspects are considered and socio-economic benefit is ensured. Therefore, dykes must be managed as an integrated coastal system and not as a single issue.

Objective of dykes

The first objective of dykes is to protect people, their activities and values from being disturbed or damaged by inundations and flooding due to typhoons or storm surges.

Thus, a dyke must be designed and constructed in such a way that it can withstand extreme events which have not occurred in the past. An extreme event such as a catastrophic typhoon may occur tomorrow, next week, next year or never! No one knows when the extreme event will arrive and thus dykes must be always safe enough to withstand such an event at any time!

Figure 1: Sea Dyke in Kien Giang Province
Dyke line

Every dyke line must be closed as a ring! If not, a dyke is almost useless; the water will find its way into the area which should be protected. It has been observed that some dyke rings in Kien Giang Province are not closed. Either the water can penetrate the canals and surround the dyke or the dyke line is interrupted by roadways or is even missing. In many cases locks and flood gates are not placed in the dyke line, or the dykes are not connected to those regulating structures. This means there are open gaps in the flood protection system. It is strongly recommended to plan the dyke system as a closed infrastructure system which can’t be surrounded or flooded by water. All structures (e.g. sluice gates, locks or crossings) in the dyke line are part of the flood protection system and should be designed with the same safety level as the dykes itself.

It is not likely to be financially feasible to construct dykes along all of the coastline and all canals to avoid flooding. In order to fulfill the main objective of dykes, that is to protect lives and economic values, the Province needs to consider the idea of establishing evacuation areas such as dwelling mounds which have a higher safety level than the dykes. This aspect is also important due to the fact that flooding in some areas can be caused due to storm surges from the coast or due to flooding of the Mekong river.

Figure 2: Dyke line

Green numbers (positive): 1 = closure of dyke line at gate; 2 = good mangroves as coastal protection; 3 = housings and infrastructures in protected area
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Red numbers (negative): 1 = Bay cut by dyke lines; 2 = missing or bad condition of mangrove belt; 3 = housings or infrastructures outside protected area; 4 = missing dyke closure; 5 = flooding

Every dyke is a three-dimensional structure. Therefore, the dyke profile, the dyke line and the closure of the dyke line must all be considered to avoid flooding of the hinterland.

Data base

Data are required as an important and valuable basis for any planning, design and maintenance of coastal dykes.

On the basis of all available data, reports and information a GIS data base should be set-up that allows rapid access by every involved institution. A GIS data base needs to be established for bathymetric surveys and current measurements. A specialized company, preferably in collaboration with a national institution of Vietnam, needs to be appointed to undertake this task. However, before undertaking such a campaign it is recommended to investigate and analyse existing studies in the area, e.g. the Mekong Delta, from which valuable data could be obtained.

The data base should contain the following information:

- Bathymetric surveys of foreshore
- Measurements of sea current and water levels
- Wind measurements
- Sediment measurements
- Wave measurements
- Geotechnical investigation
- Topographic surveys
- Satellite data
- Aero photographs
- Cadastral information (land use, owner etc.)
- Information on former site inspections and relevant documentation
- Information on relevant existing studies

These data should be freely available for all relevant institutions in the coastal zone.

Wooden fences were built to reduce the incoming currents and waves, to initiate and support siltation and to create areas for mangrove rehabilitation. These measures have been very effective in Hon Dat district and are recommended for other areas.

A good and comprehensive data base is an important and necessary base for dyke design, construction and maintenance.
Mangroves

Mangroves provide important natural coastal protection in South Vietnam. Mangroves provide an efficient damping of incoming waves and long-shore currents. In addition, the root system of mangroves strengthens the resistance of the soil against wave and current attack. Therefore, afforestation and protection of the mangrove belt is of high importance for the coastal zone.

Mangroves are threatened by natural and human factors such as waves and currents as well as shrimp farms, deforestation, urban developments, ship waves and other impacts. Therefore, the protecting mangrove belt is partly eroded or has even disappeared in Kien Giang province (Figure 3). Wooden fences were built as a mangrove protection in some areas to reduce the incoming currents and waves, to initiate and support siltation and to create areas for mangrove rehabilitation. These measures have been very effective in Hon Dat district and are recommended for other areas as well (Figure 4).

Since mangrove restoration is not the focus of this document, reference is made to the plan for erosion management, mangrove restoration and coastal livelihood for Kien Giang Province (Russell, Brown and Cuong, 2012).

Mangroves play an important role in coastal protection and are an efficient measure to protect the toe of coastal dykes and to dampen the hydraulic loads. Therefore, the restoration and rehabilitation of coastal mangroves is an important contribution to reduce costal risks.

2. Design

Hydraulic and geotechnical design is an important aspect during the planning process of coastal dykes. Dykes must be designed for extreme events with a low probability of occurrence to ensure safety during destructive events.

Design conditions

First of all, it is necessary to define the relevant design conditions. Since it is not economically feasible to design a dyke which is able to withstand all probable
events, one has to define a certain return period as a basis for design. In many cases, a return period of once in 100 years or once in 50 years is applied for the design of coastal dykes. Vietnamese guidelines recommend a return interval of once in 20 years. The definition of this design return interval depends on the economic values and the number of people in the protected area. Thus, densely populated urban areas with factories, technologies and many people require a high safety level. Rural areas can be protected with a lower safety if evacuation points are available. This means, that flooding can be allowed under special circumstances.

Coastal dykes in Kien Giang Province are expected to have a height of 3.5 m above sea water level (SWL). However, the present height is only about 2.0 m above SWL. Therefore, a need for strengthening and in some parts rising of the dyke height is obvious.

Figure 4: Mangrove rehabilitation by fences

Since it is financially impossible to increase the crest level of all dykes in Kien Giang Province up to 3.5 m above mean sea level (MSL) over a length of more than 250 km coastline, a dyke resistant to overtopping is required which is able to withstand even high overflow rates without breaching (overflow resistant dyke!). Research is required to design such a dyke taking into account the hydraulic loads, geotechnical aspects as well as other local aspects.

Relevant Studies for dyke design

The following recommendations are made to better understand the processes and as an input for coastal dyke design:
(a) Recommendations to help understand the coastal processes

- Set-up a database including the actual situation of the mangroves, the foreshore, the dykes and former storm surge events in past years based on satellite data and field survey data and to analyse the evolution.

- Conduct a bathymetric and topographic survey of the affected foreshores and the hinterland as a valuable input to the database.

![Optimum safety level](image)

**Figure 5: Optimum safety level**

- Set up a numerical current model based on field measurements of currents, water levels and bathymetry to understand the processes resulting in mangrove retreat and to explore and to identify adequate countermeasures.

- Water level statistics.

- Set-up a numerical wave model as input for dyke design to understand wave evolution and wave conditions at the dyke toe.

- Make use of the numerical model to identify efficient countermeasures to reduce mangrove erosion (to avoid a trial and error approach) and to plan suitable coastal dykes.

- Conduct geotechnical investigation in situation by drilling and taking undisturbed soil samples and in laboratory to determine material properties (grain size distribution, water content, wet and dry bulk densities, specific gravity, compressive pressure, cohesion, internal friction angle and consistency).

(b) Hydraulic design

A hydraulic design is required for every dyke. The following aspects should be taken into account for hydraulic design:
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- Determination of a design water level (DWL) and an associated return interval
- Calculation of the design waves and currents at the toe of the structure for DWL
- Assessment of the hydraulic design loads (water level, wave run-up, wave overtopping, wave impacts, etc.) (Figure 6).

The following are important factors to determine the geometry of the structure:

- Seaward slope
- Landward slope
- Freeboard height
- Crest level height and width
- Geometrical properties of berms

It is strongly recommended to construct the slopes of the dyke as smooth as possible to reduce the hydraulic loads and to increase the slope stability. This will give a safe geotechnical design. Preferably a slope inclination of 1:4 or smoother should be used in the design.

![Figure 6: Hydraulic loads of a dyke (Schüttrumpf, 2002)](image)

National and international guidelines give relevant information on sea dyke design (e.g. Eurotop (2007) or PIANC (2011)).

**Geotechnical design**

Where dykes are constructed, a suitable homogenous, erosion resistant and permeable material should be used. This should be covered by grass or gravel to avoid a loss of stability through development of cracks in the clay. Both the choice of appropriate dyke material and proof of geotechnical stability is required before construction.

As the cost of dyke construction depends on the transportation distance, it is preferable if the material is obtained from areas close-by. For dykes to be built
along the coast line or adjacent to the mangrove belt, building material should not be excavated from the seaside (foreshore) of the dyke to avoid destructive currents or high waves at the dyke toe. All of the following factors are mandatory before dyke construction:

- Identification of suitable borrow areas (clay or other building material):
- Geotechnical investigation of the material and the foundation area;
- A stability analysis of the dam body and the underground area.
- The design must consider the protection of the slopes and dyke toe to avoid erosion and undermining, it should also use filter drains to control water seepage.

3. Construction

(a) Introduction

Preferably, non-cohesive material should be used for dyke construction. Non-cohesive materials should be applied in layers with a maximum thickness of 50 cm, and be compacted layer by layer. Compaction is achieved by 3 to 5 passages of a sheep-foot vibrating roller. The degree of compaction required for non-cohesive soil material is > 97% of Proctor density (Proctor density corresponds to 100%).

In cases where different material has to be used in a zoned dyke profile, the stability against internal erosion needs to be proven. The placing of a geo-textile between the zones of different material is recommended.

A proposed construction method is shown in the figure below.

![Recommended geometry of a coastal dyke](GIZ, 2011)
The optimum water content of cohesive clay material is $w = 25\ldots 30\%$. In this case, the material should be stiff to semi-solid (hard to knead or work). If this cannot be achieved by air drying, mixing with lime (CaO) may assist in reducing the water content. The estimated quantity of lime required is approx. 18 to 22 kg/m$^2$ or 7 to 9 kg/m$^3$. It is useful to test lime dosage in a test field before commencement of construction work.

The material should be placed in layers 40 cm thick, and be compacted layer by layer. Compaction is achieved by 6 to 10 passages of a sheep-foot vibrating roller. The required degree of compaction is $\geq 95\%$ of Proctor density (Proctor density corresponds to 100%).

(b) Revetment

A revetment to protect the seaward side of the dyke against waves and currents is required. In Southern Vietnam most of these revetments consist of pattern of placed interlocking concrete blocks (Figure 9). The stability of revetments fundamentally depends on the performance of the cover layer. The ideal revetment is built on top of the seaward dyke slope consisting of four elements (Figure 8):

The dyke core

- A Geotextile
- A granular filter layer
- Concrete stones

The revetment has to be designed according to national and international guidelines (e.g. PIANC (2011) to fulfill the following requirements (Gier et al., 2012):

- Resistance against external wave load due to wave impact
- Resistance against uplift due to the wave run down
- Resistance against erosion of material of the sub-layers
- Resistance against liquefaction of the subsoil
- Adaptability to local settlements of the subsoil

Figure 8: Revetment
• Maintenance of residual resistance after an occurring damage, e.g. vandalism, to guarantee the safety of the structure

Figure 9: Interlocked pattern placed block revetment with some removed blocks

(c) Observations

Field visits to several sites along the coastline revealed weak points, failures and damages:

• Existing dyke line is in some parts not known
• Dyke lines are not closed, hence, not forming a safe flood protection system
• Locks and flood gates are not constructed as an element of the dyke line
• Mangroves are missing or mangrove belt is too narrow to protect the dyke
• Design and construction differ!
• Missing toe protection (Figure 10).
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Figure 10: Missing toe protection

- Missing geotextiles.
- Dyke slopes are too steep.
- Crest height is too low.
- Embankment materials for dyke construction have been extracted from the foreshore area causing mangrove retreat and increased hydraulic loads.
- Missing protection of dyke cover: Dykes in Kien Giang Province are constructed from fine mostly cohesive materials found in the neighborhood of dykes. This material is not erosion-resistant (Figure 11).
- Dyke material is not well compacted and easy erodible.
- Trees and bushes are found in the revetments resulting in a decrease of safety (Figure 12)
- Revetment elements are removed resulting in a missing interlocking of the elements and a reduced stability
- Bad quality of concrete
Figure 11: Erodible cover of a dyke

Figure 12: Tree in a revetment
(c) Recommendations

A number of recommendations are listed below to provide solutions and to guide dyke construction:

- Construction of an overtopping resistant dyke as a demonstration dyke
- The dyke must be constructed of homogeneous soil material according to the specified characteristics.
- Embankment materials for dyke construction shall never be extracted from the foreshore area but from adequate landside areas elsewhere.
- Before placing new embankment material the foundation area of the dyke shall be cleared of any organic or other material. Wherever required the area shall be compacted by vibrating rollers.
- Embankment material shall be placed in layers of 30 to 40 cm (for non-cohesive material max. 50 cm) achieving placing layers of approx. 20 cm after compaction.
- The dyke shall be constructed according to the proposed design by slopes of preferably 1:5 to max. 1:3 on both sides and a crest width of 6 m.
- The seaside slope shall be protected by prefabricated concrete slaps placed on gravel material. Before placing the gravel a geo-textile will be installed on the slope. Alternatively to the concrete slaps a slope protection made of rip rap (stones) can be placed.
- The dyke toe may be protected with concrete culverts filled with rock or traditional wood piling as designed. However, it is recommended to investigate the use of sheet piling with steel profiles covered by a concrete slap which could provide advantages in construction time and safety.
- Before placing new embankment or revetment material the foundation area shall be cleared of any organic or other material. Wherever required the area shall be compacted by vibrating rollers.
- Trees, roots, houses or other items in the dyke should be taken away before constructing the dyke. A strip of 5 m along the seaward dyke toe should be kept free from any construction and vegetation.
- Special attention should be paid to the intersections between seaward slope and crest to avoid backward erosion.

4. Monitoring, maintenance and repair

No dyke maintenance exists in Kieng Giang Province. As a result, coastal dykes and other coastal structures are only repaired when they fail. Such a “no maintenance philosophy” results in many dyke failures, inundated areas and extremely high repair costs. Therefore, it is strongly recommended to develop and implement a
dyke maintenance and monitoring program for coastal defense structures in Kien Giang Province.

After construction of a dyke a four step approach is traditionally applied:

- Documentation
- Monitoring
- Maintenance
- Repair

One has to distinguish monitoring, maintenance and repair. Monitoring is required to check regularly the condition of the dyke. Maintenance is required to keep the dyke in good condition. Repair is necessary when damage during a flood event occurred.

The following questions must be answered in the design of a monitoring, maintenance and repair program:

- Who is responsible and who has to execute the work?
- When is the work to be done?
- How has the work to be performed?

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<tr>
<th>Who</th>
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<td>MONITORING</td>
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<td>REPAIR</td>
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All these aspects should be defined and described in a dyke maintenance manual.

**Step 1: Documentation**

Responsible persons may change and important information will get lost. Therefore, it is absolutely necessary to collect, update and maintain all suitable information concerning all individual parts and elements of a dyke. This information must be easy to access either in digital or paper format from every responsible person. The following information must be available in such a documentation:

Maps and photos of the dyke line including the situation on the seaward and the landward side of the dyke before and after construction in regular time intervals (at least once a year).

- Plans and profiles of the dyke
- Topographic information
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- Geotechnical information
- Photos before construction
- Photos and plans during the construction time
- Special information relevant for the dyke construction

**Step 2: Monitoring**

Regular monitoring at least once a year and after storms is required to assess the condition of the dyke and the resistance against wave attack. The following aspects should be monitored:

- Damage in the dyke profile such as erosion, cracks or sliding soil
- Vegetation (like bushes or trees) which is not part of the dyke design
- Condition of structure in the dyke and the transition zones between dyke and structure
- Animals living (e.g. rats) in the dyke
- Changes in the foreshore such as erosion of the mangroves
- Any other changes which may impact the structural integrity of the dyke

It is recommended to prepare forms which can be used during the monitoring process. In addition, photos are required to monitor the present situation. Maintenance or repair measures must be defined on the basis of the monitoring results.

**Step 3: Maintenance**

To ensure the long-term performance of a coastal structure, maintenance should be considered during the planning and design process of a dyke. Maintenance depends on the type of dyke (concrete dyke, earthen dyke, etc.) and is defined as a result of the monitoring results. The following aspects should be considered and defined as rules and guidelines for dyke maintenance program:

- Yearly observation of all existing structures after the monsoon season
- Identification of weak points in coastal defense structures
- Immediate repair of coastal defense structures before the next monsoon season
- Update of information in the database
Step 4: Repair

Sometimes, repair is required to guarantee the good condition of a dyke after observed damages. Repair has to be executed as soon as possible after damage to ensure a safe dyke.

To ensure dyke safety - Monitoring, Maintenance and Repair of an existing coastal dyke are as important as the design and construction of a new dyke!

5. Final remarks

Coastal protection in Southern Vietnam and especially in Kien Giang Province is a crucial task. The area is strongly affected by storm surges and typhoons and urban and rural areas are frequently flooded. In addition, the coastal zone is very vulnerable to the consequences of climate change, especially due to sea level rise and the expected increase of the frequency and intensity of extreme events. Therefore, sustainable planning, design, construction and maintenance of coastal dykes in Kien Giang Province is required to find an optimum between costs and safety!

Currently the design, construction and maintenance and thus the present state of the coastal dykes in Kien Giang are not in agreement with national or international guidelines and recommendations. This is likely to widespread throughout Vietnam.

Weak points, failures and damage as well as the lack of closure of the dyke rings or missing maintenance were found during two site visits in Kien Giang Province. Therefore, this report is intended:

- to provide technical assistance!
- to convince donors of the necessity to help the Province!
- to help GIZ and Australian AID to assess the situation in five coastal provinces and to optimize their contributions and input!
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Figure 11: Perfect mangroves as a protection of the dyke toe

References


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