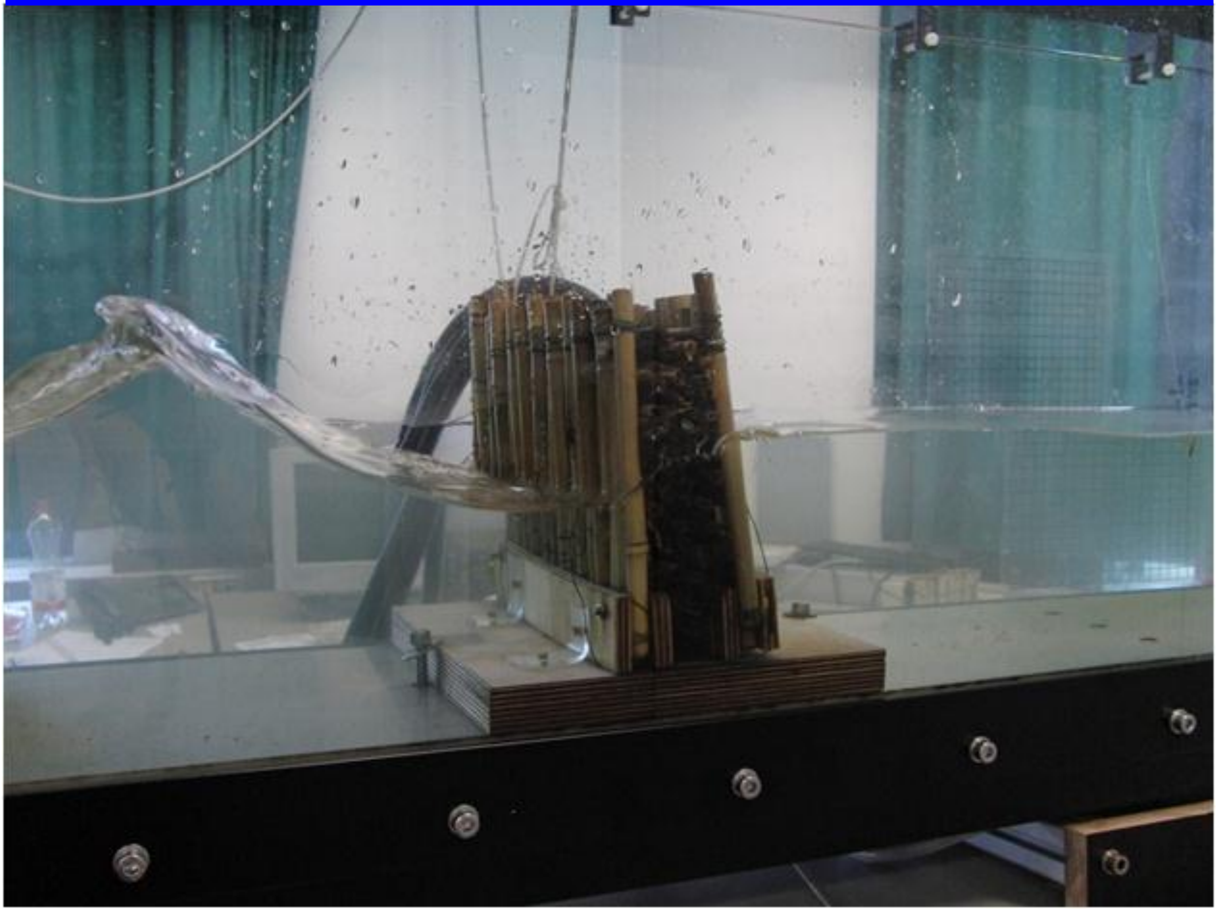
August 2011

Ingenieurgesellschaft
von Lieberman
» Bauen und Umwelt «

CZM Soc Trang, Vietnam
Design of Breakwaters



giz

COOPERATION
FEDERAL REPUBLIC OF GERMANY
SOCIALIST REPUBLIC OF VIETNAM

SỞ NÔNG NGHIỆP VÀ PTNT SÓC TRĂNG

Management of Natural Resources in the Coastal Zone of Soc Trang Province, Vietnam

Detailed Design of Breakwaters

47 Pages, 14 Attachments

Project:	Management of Natural Resources in the Coastal Zone of Soc Trang Province, Vietnam 134 Tran Hung Dao Street Soc Trang City, Viet Nam
Client:	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH Dag-Hammarskjöld-Weg 1-5 65760 Eschborn, Germany
Design:	von Lieberman GmbH Ruhrstraße 57 22761 Hamburg, Germany Tel.: 040 / 500 993-0 Fax: 040 / 500 993-33
Contact Person:	Dipl.-Ing. Thorsten Albers (Expert River and Coastal Engineering)
Project Number:	13713-01

Hamburg, 23.08.2011

Deutscher Akkreditierungs Rat
DAR
DAP-PL-3797.00

TABLE OF CONTENTS **Page**

1 INTRODUCTION 8
1.1 Background 8
1.2 Scope of work 9
2 BOUNDARY CONDITIONS 11
2.1 Waves 11
2.2 Current velocities 12
2.3 Wind 12
2.4 Soil 12
3 PRELIMINARY DESGIN 14
4 MATERIAL CHARACTERISTICS OF BAMBOO 16
4.1 Literature review 16
4.2 Material parameters 17
4.3 Fracture behaviour 18
5 STATIC DESIGN 19
5.1 Current- and wave-induced loads 19
5.1.1 Single piles 19
5.1.2 Wall 20
5.2 Breaking waves 21
5.3 Impacts 22
5.4 Man weight 22
5.5 Wind load 22
6 GEOTECHNICAL DESIGN AND PROOF OF STRUCTURAL SAFETY 24
6.1 Vertical forces 24
6.2 Horizontal forces 26
7 PLANS 32
7.1 Site maps and description 32
7.2 Front views, cross sections and top views 32
7.3 Details 33
8 CONSTRUCTION PROGRESS 34
8.1 Preparation and site facilities 34
8.2 Installation 34
8.3 Construction sequence 37
8.4 Drainage system 37
9 AMOUNT OF MATERIAL 39
10 CONSTRUCTION SUPERVISION 41
10.1 Tensile tests 41

11 OUTLOOK 44
12 REFERENCES..45
13 ATTACHMENTS...47

LIST OF FIGURES

Figure 1: Grain size distribution at the coast of Vinh Tan ... 13
Figure 2: Recommended combination of bamboo breakwater and bamboo fences ... 15
Figure 3: Lateral view of the bamboo fences and the bamboo breakwater (scheme); viewing direction: north-east ... 15
Figure 4: Calculational cross section of a bamboo pile ... 18
Figure 5: Computed non-breaking wave forces on vertical walls ... 21
Figure 6: Illustration of the subgrade reaction method incl. static system, bending line, horizontal soil pressure and bending moment ... 26
Figure 7: Distribution of the momentum into a force couple ... 29
Figure 8: Joint made with rattan strips (DUNKELBERG, 2000) ... 33
Figure 9: Sharpened round timber with a handle bar for the preparation of the installation (left), head ram for the installation of the vertical piles ... 35
Figure 10: Installation of vertical piles using a pile-driving machine or a dredger bucket ... 35
Figure 11: Steel lance for the installation of the vertical piles with water pressure ... 36
Figure 12: Drainage network in a main field ... 38
Figure 13: Cross-section of main and minor ditches of the drainage system ... 38
Figure 14: Setup of the tensile tests (2 options of abutment) ... 42
Figure 15: Tension belt including belt spanner (left), crane weigher (right) ... 43

LIST OF TABLES

Table 1: Simulated waves at Vinh Tan during southwest and northeast monsoon 11
Table 2: Comparison of test results 17
Table 3: Material parameters applied in the design process 17
Table 4: Calculation of M_{max}, z_M, max σ, and z_σ for the different loading cases 28
Table 5: Estimated amount of material for the breakwater and the bamboo fence 39

LIST OF ATTACHMENTS

Attachment 1: Site map with background

Attachment 2: Site map without background

Attachment 3: Site map with control points

Attachment 4: Cross-section breakwater/longshore fence

Attachment 5: Side view breakwater/longshore fence

Attachment 6: Top view breakwater/longshore fence

Attachment 7: Cross-section cross-shore fence

Attachment 8: Side view cross-shore fence

Attachment 9: Top view cross-shore fence

Attachment 10: Top view connection longshore/cross-shore fence

Attachment 11: Top view connection cross-shore fence/revetment

Attachment 12: Side view cross-shore fence incl. connection to revetment

Attachment 13: Details cross-section breakwater/longshore fence and side view breakwater/longshore fence

Attachment 14: Details cross-section cross-shore fence and side view cross-shore fence

1 INTRODUCTION

1.1 Background

Along the coastline of Soc Trang Province, Viet Nam, dynamic processes of accretion and erosion occur influenced by interactions between:

- the discharge regime of the Mekong Delta,
- the tidal regime of the South China Sea and
- the monsoon weather patterns of Southeast Asia.

Coastal erosion and accretion are complex processes depending on various influences. Key elements are the sediment transport under the influence of currents and waves, the overall dynamics of beaches in a coastal section and anthropogenic impacts.

Due to its vectorial character, the sediment transport at the coast may be divided into:

- cross-shore sediment transport (on-/offshore transport)
- longshore sediment transport.

Coastal cross-shore sediment transport induces short-term morphologic changes of sediments, e.g. during storm events. Coastal longshore transport causes long-term morphologic changes of a coastal section.

In some areas, such as the focus area of Vinh Tan Commune, severe erosion endangers the dyke and consequently the people and farmland located behind the dyke.

The morphodynamics in the focus area of Vinh Tan have been investigated and analysed in a study executed by the Hamburg University of Technology in 2009 and 2010 (ALBERS & VON LIEBERMAN, 2011).

In collaboration with the Southern Institute of Water Resources Research (SIWRR), available data with relevance to the coast of Soc Trang were researched and analysed. Although data on the bathymetry, water levels, river discharges and sediment freights were available, essential data about the erosion site, especially about the wave climate, were missing. Therefore, measurement campaigns were carried out to close this gap and build the foundation for sophisticated and effective erosion protection measures. Over the course of three measurement campaigns, information about currents, waves, sediment concentrations and the bathymetry

were recorded. The field measurements covered different seasons including the northeast and southwest monsoons.

The wave measurements showed a clear dependency on the monsoon season. Recorded currents show a long-shore component due to the approach of the tidal wave along the South Vietnamese coast. These currents are increased by the northeast monsoon.

The available and generated databases were used to set-up, calibrate and verify different numerical models. Shoreline changes were computed considering various erosion protection measures. Besides conventional techniques, an alternative approach using local materials was investigated.

Along the southeast coast of Viet Nam, natural erosion and accretion alternate across different sections. The exposed coastline is affected by long-shore flood currents, off-shore directed ebb currents and waves. Periods with increased wave activity will increase the erosion rate, whereas periods with decreased wave activity may even lead to accretion. During the northeast monsoon, lower sediment supply from the Mekong, stronger currents and higher waves increase erosion. In places where the overgrown foreland disappeared, severe erosion can endanger the stability of the dykes over time, even after periods of temporary accretion.

1.2 Scope of work

All coastal protection or erosion protection measures – except from beach nourishment – cause downdrift erosion. Hard coastal protection measures should only be applied if human lives or larger monetary values are endangered. In general additional nourishment is necessary to reduce the negative effects of the installed structures. Coastal erosion protection has to be designed carefully to secure the desired effects and minimize downdrift erosion. A close to nature solution is worthwhile.

In the current and erosion modelling survey, different arrangements and designs of erosion protection measures were investigated by means of numerical and physical modelling. In addition to the application of conventional breakwaters, adapted approaches using local materials were investigated. In conclusion, recommendations for erosion protection measures were given based on the model results, the field measurements and a cost analysis.

The use of local materials like bamboo has many advantages based on its strength, availability and costs. Using a breakwater made of bamboo the desired wave transmission can be

achieved. Therefore, the construction of bamboo breakwaters is recommended. Furthermore, the costs of this solution are low, compared to the other options.

All constructions designed in this report (breakwater, longshore and cross-shore fences) have to be made from bamboo.

Before constructing the recommended and agreed upon solution, a practical plan has to be provided. This document provides detailed plans of the construction containing all accurate positions, dimensions and construction details in the form of site maps, cross sections and top views. All static and geotechnical verifications are done. For the construction phase, several measures of quality control, e.g. experimental identification of the breaking force of the bamboo and verification of a sound installation of the bamboo piles, are proposed.

This document provides the product specifications for the construction. Mass and cost calculations included in the submitted quotations must be verified based on local prices. During the construction, supervision of the tensile tests of the bamboo piles must be carried out to quantify the breaking forces of single piles and pile groups. The depth of embedment of the piles must be controlled as well as the construction materials. A detailed documentation of the construction phase is essential.

The construction of the bamboo breakwater and bamboo fences in Vinh Tan serves as a pilot project for erosion protection and mangrove rehabilitation in erosion sites, which will also be used to gain knowledge for future application and optimisation through detailed documentation and monitoring.

2 BOUNDARY CONDITIONS

ALBERS & VON LIEBERMAN (2011) provide a detailed description of the investigation area, its hydrology and morphodynamics. Here, only the relevant loads are summarised. The values were derived from available data and time series, field measurements and numerical modelling. For details see ALBERS & VON LIEBERMAN (2011).

2.1 Waves

The wave model was calibrated and verified using wind data, data from available gauges and data from field measurements. Different scenarios were simulated. In one scenario, storm conditions during the southwest monsoon were simulated with peak wind velocities of 16 m/s. In that scenario, significant wave heights of 0.58 m were predicted at Vinh Tan. The average wave direction at Vinh Tan is from south-southwest during that event.

Another model run simulated waves during the northeast monsoon season with peak wind velocities of 25 m/s. For the coast at Vinh Tan, significant wave heights of 0.63 m were computed. Although the wind velocity is higher than in the southwest monsoon scenario, the waves are not significantly higher, because Vinh Tan is located in the wave shadow of the Mekong Delta with its sandbanks.

The wave parameters for different scenarios are summarised in Table 1.

Table 1: Simulated waves at Vinh Tan during the southwest and northeast monsoon

			Simulated	
Scenario	Wind direction [°]	Wind speed [m/s]	Peak period T_P [s]	Sign. wave height H_S [m]
1a	SW	16.28	6.04	0.58
1b	WSW	18.90	6.04	0.58
1c	W	15.75	9.70	0.54
2a	NNE	20.53	5.50	0.52
2b	NE	25.24	5.50	0.63

For the design of the breakwaters, a significant wave height of 0.65 m and a peak period of 5.5 s can be taken as a basis. Waves may approach from different angles. The maximum wave height is calculated as

$$H_{max} = 1.86 \cdot H_S = 1.21m$$

based on the theory of LONGUET-HIGGINS (cf. EAK, 2002) assuming an event with 1000 waves.

The maximum wave height can only be achieved at respective water depths, taking wave breaking into account.

2.2 Current velocities

The current velocities in the investigation area are mainly influenced by tides. The tidal range is 3.50 m leading to water depths up to 1.50 m at tidal high water at the position of the projected breakwater. The results of both the field measurements and the numerical modelling were used to define the current parameters.

During the northeast monsoon season in January 2010 the stationary installed AWAC recorded current velocities between 0.10 m/s and 0.60 m/s during floods. The peaks in current velocity during ebb tide were less pronounced, between 0.10 m/s and 0.40 m/s.

The mobile ADCP surveys showed seaward currents during ebb tide of around 0.40 m/s and maximum long-shore currents during flood tide of approximately 1.00 m/s, whereas the largest values were measured further offshore.

The hydrodynamic model computed current velocities between 0.20 and 0.50 m/s in the nearshore area. Therefore, the model results and the current measurements in the focus area show a good correlation.

For the design of the breakwaters a current velocity of 0.50 m/s is assumed.

2.3 Wind

One possible loading case for the design of the bamboo breakwater is when high wind velocities occur during low water and full exposure of the breakwater. For this case a design wind velocity of 25 m/s according to scenario 2b (cf. chapter 2.1) based on available data sets is assumed.

2.4 Soil

Samples of bed material were analysed in a geotechnical laboratory. Figure 1 shows the grain size distribution of two bed samples on the coast of Vinh Tan.

The median grain size is 0.0065 mm. The bed material is clayey silt. Further samples of the bed material in the focus area show silty and clayey material with a median grain diameter (D_{50}) between 0.003 and 0.007 mm.

Based on samples from the investigation area, the thickness of that soft soil layer is approximately 0.80 m. Under that layer, there is a higher consolidated sand layer. Due to erosion or accretion, the thickness of the soft soil layer may vary across a range of decimetres. Before the construction, the elevation of the bed level and thickness of the soft soil layer should be determined at relevant positions.

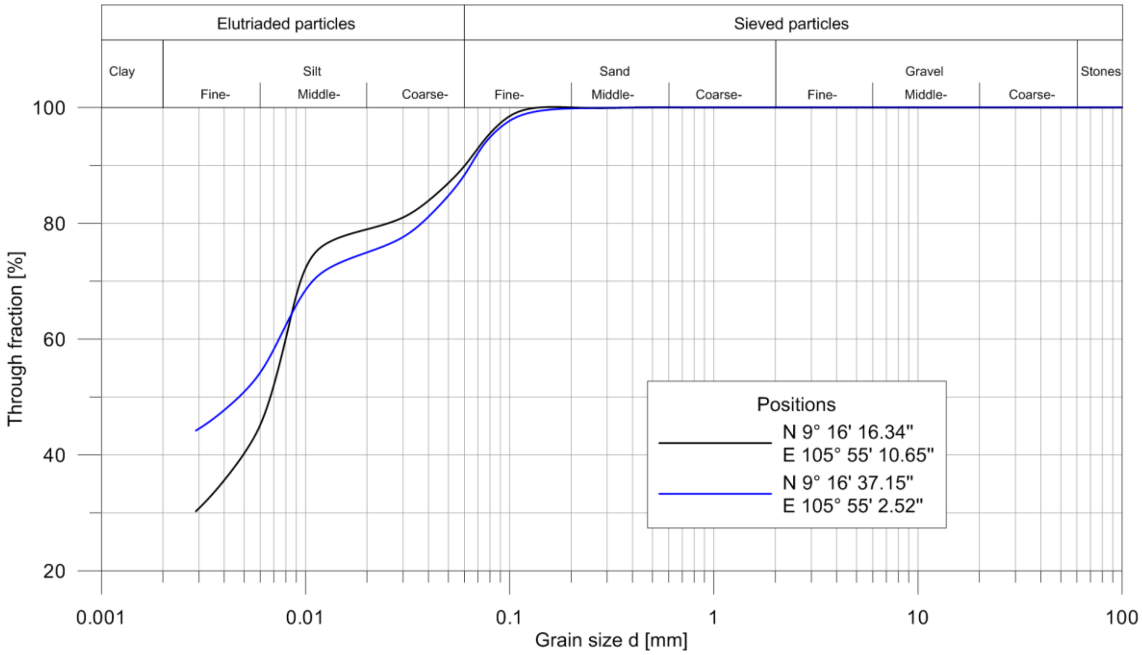


Figure 1: Grain size distribution at the coast of Vinh Tan

3 PRELIMINARY DESGIN

The aim of the structural measures is to reduce erosion and to increase accretion. Negative effects like downdrift erosion must be avoided as much as possible.

At the endangered dyke in the focus area, a section of approximately 200 m has to be protected. Different arrangements of breakwaters were tested based on various simulations (ALBERS & VON LIEBERMAN, 2011).

The construction of breakwaters always leads to downdrift erosion. This effect is minimized if one breakwater is installed with a length of 100 m at a distance of 50 m from the idealized shoreline. The transmission coefficient should be around 0.50. The desired wave transmission can be achieved with a breakwater made of bamboo. The results of the respective physical modelling can be found in ALBERS & VON LIEBERMAN (2011). The application of local materials like bamboo has many advantages due to its strength, availability and costs. Therefore, the construction of the bamboo fence is recommended. Furthermore, the costs of this solution are low compared to the other options.

If the gaps between the eroded floodplains at the endangered dyke are closed, the wave energy will dissipate on the newly developed floodplain and the dyke will be protected from erosion. Closing the gaps will create a close to nature situation, with no significant resulting downdrift erosion. Therefore, a chequered arrangement of bamboo fences at the dyke is recommended in combination with a bamboo breakwater parallel to the coast.

Figure 2 shows the accordant arrangement. A sound monitoring will lead to detailed information about the effectiveness of both measures.

The length of the bamboo fences indicated in Figure 2 adds up to approximately 400 m. The length of the bamboo breakwater is 100 m.

Figure 3 shows diagrams of the lateral views of the bamboo fences and the bamboo breakwater.

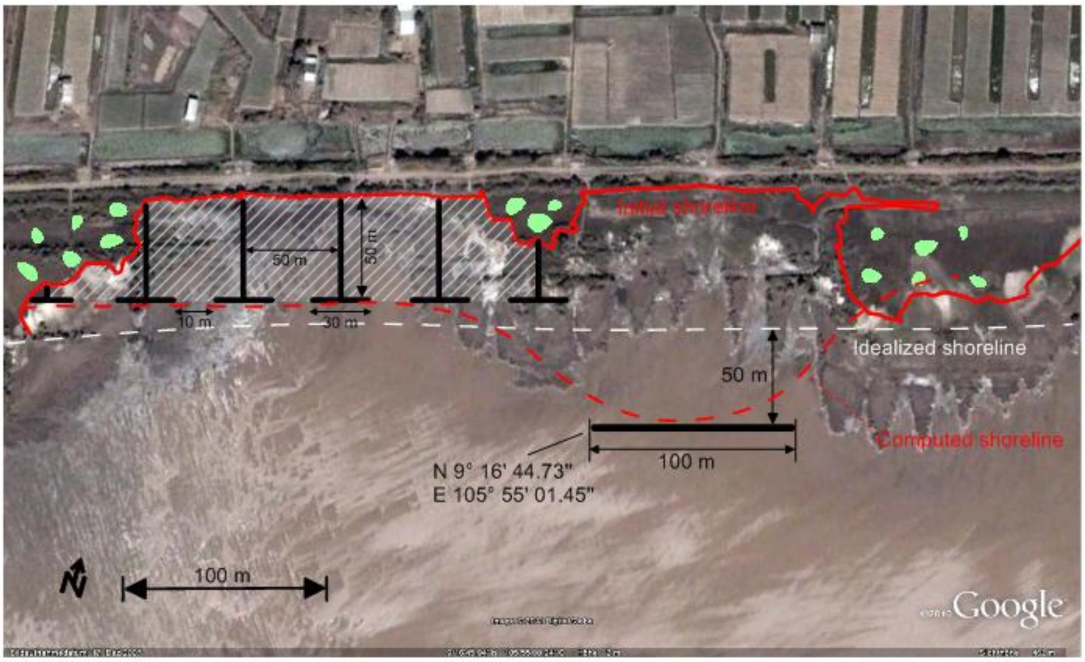


Figure 2: Recommended combination of bamboo breakwater and bamboo fences

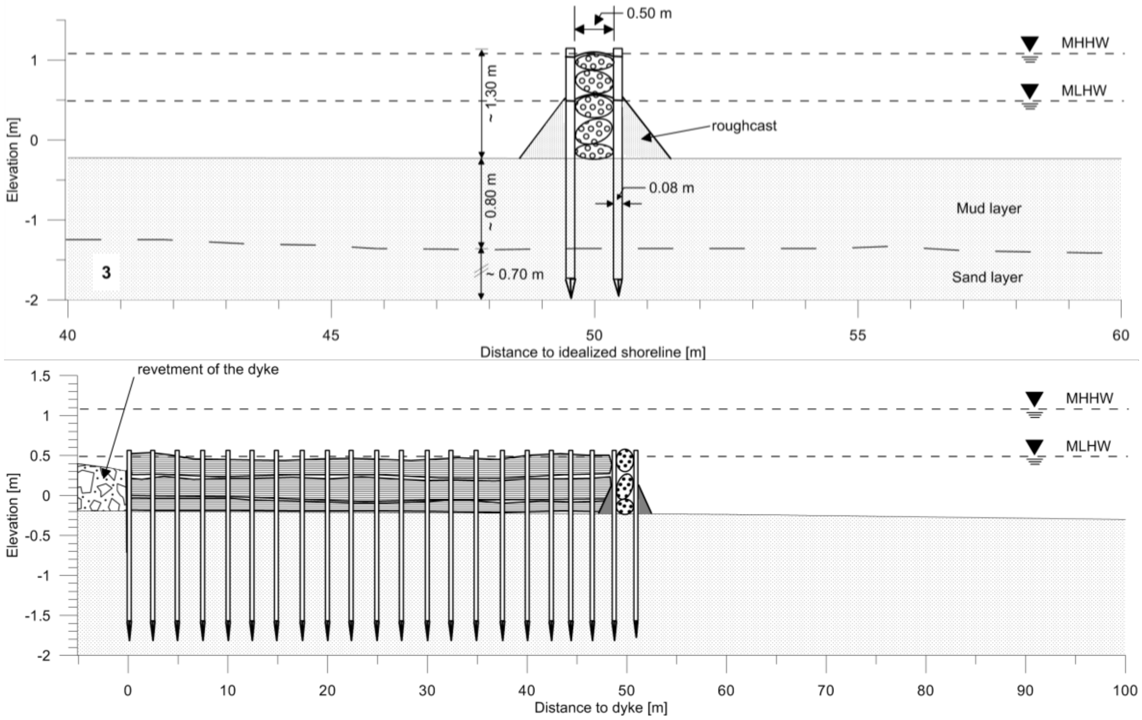


Figure 3: Lateral view of the bamboo fences and the bamboo breakwater (scheme); viewing direction: north-east

4 MATERIAL CHARACTERISTICS OF BAMBOO

It is known that the mechanical properties of solid timber are affected by climatic and soil conditions, location, age, time of felling, moisture content etc. Furthermore, there are considerable variations over the length of the trunk or its cross-section. The strength of the timber also depends on the directions of the forces (parallel or perpendicular to the direction of the fibres).

The variation in strength values of bamboo as a hollow cylinder with different material thicknesses within the cane wall and the nodal diaphragms perpendicular to this wall, is almost even larger. A precise picture of these values may only be obtained through data from bamboo strips and bamboo canes. Several sources were compiled and compared before the detailed design of the breakwaters, in the context of a literature review.

The space in between the two rows of bamboo piles is filled with available brushwood. The brushwood must calm the currents and dissipate wave energy and has to be permeable enough to let fine sediment particles enter the fence fields.

4.1 Literature review

To evaluate and compare the material characteristics of bamboo, its origin, age, humidity content and the diameter of the tube are of high importance. Comparing results of various investigations on the properties of bamboo, a certain fluctuation in results is evident, although all tests were conducted with the same species of bamboo (guadua angustifolia).

The results of different studies can be found in relevant literature:

- ATROPS, 1969
- HIDALGO, 1974
- JANSSEN, 1981
- JANSSEN, 1990
- LINDEMANN & STEFFENS, 2000
- AICHER, 2000
- DUNKELBERG, 2000

4.2 Material parameters

The results of the different studies vary in a certain range. Table 2 shows the relevant material parameters of different published research results.

Table 2: Comparison of test results

[kN/cm²]	**Tensile strength**	**Compressive strength**	**Elastic modulus**	**Bending strength**
Lindemann & Steffens (2000)	14.8 – 38.4	6.2 – 9.3	2,000	7.6 – 27.6
Aicher (2000)	–	5.6	1,840	7.4 – 10
Hidalgo (1974)	19.19	3.93	2,150	–
Janssen (1981)	–	–	1,760	14.48

Detailed material testing is not intended within the context of the designing of the bamboo breakwaters. The values applied in the design process are conservative assumptions (cf. Table 3).

Table 3: Material parameters applied in the design process

Parameter	[kN/cm²]
Elastic modulus	1,800
Tensile strength	15.0
Compressive strength	3.9
Bending strength	7.6

For the design, the dimensions shown in Figure 4 are assumed. The calculational diameter of 0.075 m considers deviations from the nominal diameter of 0.08 m.

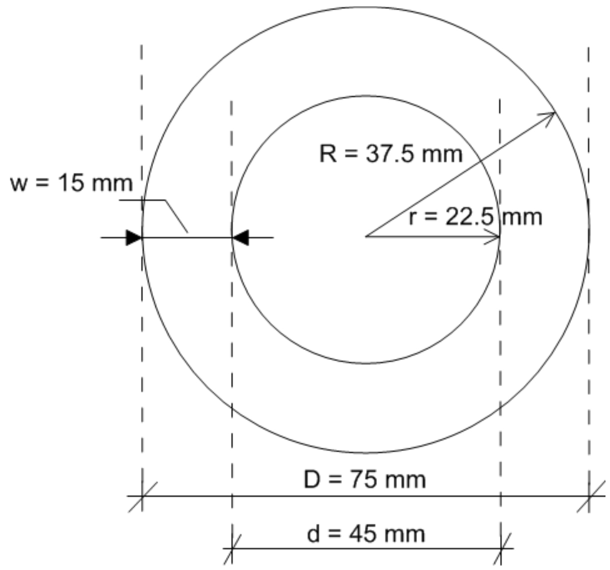


Figure 4: Calculational cross section of a bamboo pile

The relevant area of a cross section is calculated as:

$$A = \left[\frac{D^2\pi}{4}\right] - \left[\frac{d^2\pi}{4}\right] = \left[\frac{7.5^2\pi}{4}\right] - \left[\frac{4.5^2\pi}{4}\right] = 28.27\ cm^2$$

The 2nd order area moment is calculated as:

$$I = \frac{\pi}{4}(R^4 - r^4) = \frac{\pi}{4}(3.75^4 - 2.25^4) = 135.2\ cm^2$$

4.3 Fracture behaviour

The fracture behaviour of common timber differs significantly from the fracture behaviour of bamboo. The failure of several fibres of timber leads to the fracture of the cross section. Cracks in bamboo are deflected in the direction of the fibres and the energy of the impact is dissipated. The development of longitudinal cracks is hindered by the nodes of the bamboo, which leads to an increased fracture toughness of the material. Exceeding the bearing strength does not lead to abrupt fractures. This is important for the design and the tensile tests.

5 STATIC DESIGN

The design of the bamboo breakwater and bamboo fences is done based on available design approaches. The breaking force is estimated based on relevant literature (cf. chapter 4). In addition, during the construction the breaking force of several bamboo piles should be determined experimentally to confirm the assumed values. A sound installation of the piles into the ground is essential.

5.1 Current- and wave-induced loads

5.1.1 Single piles

The front row of bamboo piles is directly loaded by currents and waves. The calculation of the loads resulting from currents and waves is done based on the superposition method by Morison, O'Brian, Johnson and Schaaf (MOJS). The current forces and acceleration forces of the tidal current and the waves result from the following formula (EAK, 2002):

$$f_{total} = f_D + f_M = C_D \cdot \frac{1}{2} \cdot \rho_W \cdot D \cdot u \cdot |u| + C_M \cdot \rho_W \cdot \frac{\pi \cdot D^2}{4} \cdot \frac{du}{dt}$$

f_{total} = Sum of current force and acceleration force [kN/m]

f_D = Current force on the pile [kN/m]

f_M = Acceleration force on the pile [kN/m]

C_D =Current resistance coefficient [-]

C_M = Inertia resistant coefficient [-]

ρ_W =Density of water [t/m³]

D = Diameter of the pile [m]

u = Horizontal component of current/orbital velocity [m/s]

$\frac{du}{dt}$ = Horizontal component of current/orbital acceleration [m/s²]

The total load on the pile is determined by solving the integral of the calculated line forces. The different parts of the wave load are dephased. Different phases of the wave passage have to be considered.

Based on physical tests, the coefficients C_D and C_M were determined by CERC (1984) for different Reynolds-Numbers:

$$C_D = 0.75$$

$$C_M = 1.8$$

<u>Tidal currents:</u>

$$f_{total} = 0.75 \cdot \frac{1}{2} \cdot 1.03 \cdot 0.075 \cdot 0.3^2 + 1.8 \cdot 1.03 \cdot \frac{\pi \cdot 0.075^2}{4} \cdot (1.04 \cdot 10^{-5})^2 = 0.0026\ [kN/m]$$

<u>Waves:</u>

1. Loading case: Maximum orbital velocity

$$f_{total} = 0.75 \cdot \frac{1}{2} \cdot 1.03 \cdot 0.075 \cdot 0.965^2 + 1.8 \cdot 1.03 \cdot \frac{\pi \cdot 0.075^2}{4} \cdot 0^2 = 0.027\ [kN/m]$$

2. Loading case: Maximum orbital acceleration

$$f_{total} = 0.75 \cdot \frac{1}{2} \cdot 1.03 \cdot 0.075 \cdot 0^2 + 1.8 \cdot 1.03 \cdot \frac{\pi \cdot 0.075^2}{4} \cdot 1.21^2 = 0.012\ [kN/m]$$

3. Loading case: Combination

$$f_{total} = 0.75 \cdot \frac{1}{2} \cdot 1.03 \cdot 0.075 \cdot 0.682^2 + 1.8 \cdot 1.03 \cdot \frac{\pi \cdot 0.075^2}{4} \cdot 0.857^2 = 0.020\ [kN/m]$$

The design load results from the tide and first loading case of the wave load and adds up to 0.03 kN/m. For a bamboo pile 1.30 m in length, the resulting force is 0.04 kN.

5.1.2 Wall

The rear row of bamboo piles is loaded by the horizontal current- and tide-induced forces transmitted by the brushwood wall. The calculation of the resulting loads is done using the Coastal Engineering Design and Analysis System (CEDAS) based on the approaches of Miche-Rundgren and Sainflou. The results of the calculation are summarized in Figure 5.

Case:

Nonbreaking Wave Forces at Vertical Walls

Depth from SWL:	1.30 m
Incident wave height:	0.65 m
Wave period:	5.50
Wave reflection coeff:	0.50
COTAN of nearshore slope:	1000.00
Breaking coefficient:	0.78

	Miche-Rundgren		Sainflou		
Wave position at wall	Crest	Trough	Crest	Trough	Units
Height above bottom:	2.28	1.31	2.28	1.31	m
ltegrated force:	22.91	7.44	19.92	2.95	kN/m
Integrated moment:	17.11	3.17	13.99	0.81	kN-m/m

NOTE: Sainflou results are recommended for this case.

Figure 5: Computed non-breaking wave forces on vertical walls

Applying the Sainflou approach, the resulting integrated horizontal force is 20 kN per metre width. This maximum load occurs at the crests of the waves. With a distance of 0.10 m between the vertical bamboo piles, this results in a horizontal force on each bamboo pile of 2 kN.

5.2 Breaking waves

Breaking waves can induce high compression stresses on piles in the front row above the static water level. These “slaps” or “slams” appear for very short times (in the range of milliseconds) and therefore are not important for the total design. For local loads in the area of the static water level the slamming forces need to be considered.

The slamming force results to:

$$F_S = C_s \cdot \frac{1}{2} \cdot \rho_w \cdot D \cdot u_{max}^2 \cdot \lambda \cdot \eta_b = 2 \cdot \pi \cdot \frac{1}{2} \cdot 1.03 \cdot 0.075 \cdot 0.965^2 \cdot 0.5 \cdot 0.45 = 0.051\ kN$$

F_S = Slamming force [kN]

$C_S = 2\pi$ = Slamming coefficient [-]

ρ_W = Density of the water [t/m³]

D = Diameter of the pile [m]

$\lambda = 0.5$ = curling factor [-]

η_b = maximum water level of the breaker above the static water level (app. 0.7 · H_s) [m]

u_{max} = maximum horizontal component of the orbital velocity [m/s]

The structure of the brushwood absorbs the energy resulting from slams. Therefore, the influence of breaking waves on the brushwood is neglected.

5.3 Impacts

Abnormal forces can result from the impact of floating items like flotsam or vessels. International standards for the certification of mobile flood protection walls assume the impact of a 300 kg item for the approval of the systems. This value is also considered as sufficient for the static design of the bamboo constructions taking into account the boundary conditions like water depth and external circumstances.

The maximum impact is calculated as:

$$F_{impact,max} = \frac{u \cdot m}{t} = \frac{0.3 \frac{m}{s} \cdot 300kg}{2s} = 45\ kN$$

A maximum velocity of the floating items of 0.3 m/s (cf. 2.2) is assumed. The flexible structure of the construction allows for assuming a dwell time of the impact of 2 s.

5.4 Man weight

The consideration of forms of vandalism is covered with 5.3.

Additionally a man weight of 1 kN as a vertical load is assumed for each bamboo pile based on German Standards (DIN 1055, Part 3).

5.5 Wind load

On the North Sea Coast, long and slender tree trunks are used to mark navigation channels in the Wadden Sea. There are reported cases in which the trunks failed during storm conditions and low water. Although these trunks are much more exposed to the wind due to their length above ground, this loading case is proofed here.

The front row of bamboo piles is directly loaded by the dynamic wind pressure. The force on a single bamboo pile is calculated as:

$$f = C_D \cdot \frac{1}{2} \cdot \rho_{Air} \cdot D \cdot u \cdot |u| = 0.75 \cdot \frac{1}{2} \cdot 1.204 \cdot 10^{-3} \cdot 0.075 \cdot 25^2 = 0.021\ kN/m$$

If the bamboo fence is regarded as a permeable wall, the rear row of bamboo piles is loaded by the dynamic pressure based on German Standards (DIN 1055, Part 4) and calculated as:

$$w = c_f \cdot q = 0.5 \cdot 0.5\ kN/m^2 = 0.25\, kN/m^2$$

The values c_f and q are estimated based on German Standards. The result has to be divided by the number of piles per metre to get the force on one pile per metre height. The difference to the calculation for a single pile above results from the influence of the brushwood. With a distance of 0.10 m between the vertical piles the resulting force on a single pile is approximately 0.04 kN.

6 GEOTECHNICAL DESIGN AND PROOF OF STRUCTURAL SAFETY

In constructional engineering, piles with small diameters usually are designed as piles with axial applied loads. The piles of the bamboo breakwaters are also designed to absorb momentum. Therefore, horizontal loads are transferred to the ground by an elastic clamping of the pile. Thus, the static system is a bending resistant pile backed by the surrounding soil. In practice the *subgrade reaction method* is accepted. It is assumed that the horizontal pressure between the pile and the soil is proportional to the horizontal displacement of the pile. The proportionality factor k_s (bedding modulus) can vary with the depth, whereas the well known parable of Titze offers a good description of the distribution of k_s (cf. ARZ ET AL., 1991).

The load bearing behaviour in the axial and horizontal directions is calculated first of all for detached single piles. If the piles are arranged in groups they influence each other in terms of load transmission. If the piles are arranged very close to each other, the soil between them is distorted. Due to the lack of sustainable calculation methods for the present case, the load bearing behaviour of those piles has to be determined by tests.

For the geotechnical design, the characteristics of the sand layer are applied. The depth of embedment refers to the depth in the sand layer. The mud layer is assumed to be a buffer layer that can grow and shrink due to external circumstances like increased or decreased incoming wave energy and that does not have load-bearing attributes. Furthermore, the mathematical description of the mud layer is very uncertain.

The geotechnical design and the proof of structural safety are primarily carried out for the bamboo breakwaters and the longshore bamboo fences. These structures dissipate the main wave and flow energy as well as possible impacts of floating items. The diameter of the bamboo piles of the cross-shore fences can be chosen one size smaller due to the reduced loads. Therefore, the most visible parts of the erosion protection will appear less massive. Furthermore, this adjustment will reduce costs.

6.1 Vertical forces

The compressive force parallel to the bamboo fibres resulting from man weight is:

$$\frac{F}{A} = \frac{1\ kN}{28.27\ cm^2} = 0.0354\ \frac{kN}{cm^2} < 3.9\ \frac{kN}{cm^2}\ ✓$$

Therefore, the proof of the compressive strength of a bamboo pile due to the man load is given.

Vertical forces occur due to man weight. The jacket friction must be large enough to carry that man weight. It is dependent on the depth of embedment. The man weight is assumed to occur during low water, while no lift forces are effective in the opposite direction.

The depth of embedment is calculated as:

$$x > \frac{F}{c_u \cdot l} = \frac{1\,kN}{25\,kN/m^2 \cdot 0.23\,m} = 0.18\,m$$

c_u = coefficient for sand with fine grains, undrained, cohesion

$l_{Bamboo} = \pi \cdot d = \pi \cdot 0.075\,m = 0.23\,m$ = Perimeter of the bamboo pile

The loading case *vertical forces due to the man weight* are not significant for the depth of embedment.

The lift force of a single bamboo pile during high water is 168 N and therefore significantly smaller than the man weight.

$$A_{lift} = (\rho_w \cdot g \cdot V_w) - (\rho_B \cdot g \cdot V_B) = 168\,N$$

$\rho_w = 1030\,\frac{kg}{m^3}$ = density of water

$g = 9.81\frac{m}{s^2}$ = gravitational acceleration

$V_w = 4.7\,m \cdot \pi \cdot \left(\frac{0.075^2 m^2}{4}\right) = 0.021 m^3$ = volume of the displaced water

$\rho_B = 350\,\frac{kg}{m^3}$ = density of bamboo

$V_B = 4.7\,m \cdot 2.827 \cdot 10^{-3} m^2 = 0.013 m^3$ = volume of the displaced water

Thus, the depth of embedment resulting from the man weight is large enough to activate the jacket friction effective in the opposite direction of the lift force. The lift forces of the horizontal bamboo bars and the brushwood are distributed over several vertical piles and can be neglected because the depth of embedment will have to be significantly larger than 0.18 m due to the horizontal forces.

6.2 Horizontal forces

It is assumed that a standard bamboo pile with a length of 4.70 m is used. The crest of the breakwater should be on the level of the daily tidal mean high water level. Based on the latest existing data, that means an above ground height of 1.30 m. A mud depth of 0.80 m is assumed. The resulting depth of embedment in the sand layer is 2.60 m. The geotechnical and static calculation is done assuming a depth of embedment of 3.40 m (in mud and sand) for the calculation of the momentum in the pile and a depth of embedment of 3.00 m (2.60 m in sand and a computational value of 0.5 · 0.80 m in mud) for the calculation of the horizontal soil pressure.

The bedding modulus k_s depends on the depth and varies for different kinds of soil. Relevant literature provides reference values. These should be determined by test loads during the construction.

The bedding modulus can be derived from the following expression of the horizontal soil pressure:

$$\sigma = k_s \cdot w$$

Figure 6 shows an illustration of the subgrade reaction method including the static system, the bending line, the horizontal soil pressure and the bending moment.

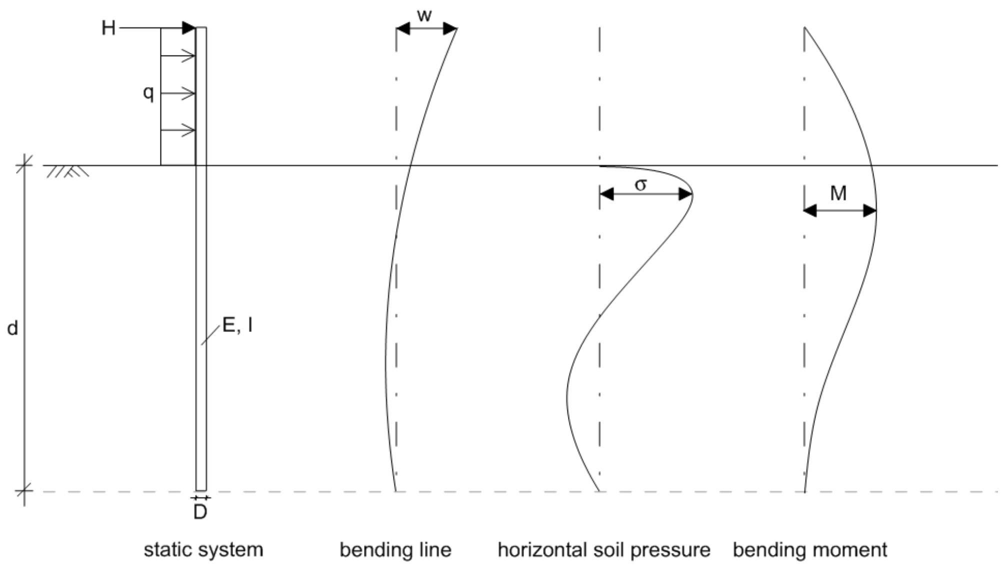


Figure 6: Illustration of the subgrade reaction method including static system, bending line, horizontal soil pressure and bending moment

The maximum momentum in the bamboo pile is calculated as:

$$M_{max} = H \cdot d \cdot \alpha$$

whereas the position of the maximum momentum is:

$$z_M = d \cdot x_M$$

The maximum horizontal soil pressure is calculated as:

$$max\ \sigma = \frac{H}{D \cdot d} \cdot \beta$$

whereas the position of the maximum horizontal soil pressure is:

$$z_\sigma = d \cdot x_\sigma$$

The following coefficients and values are applied:

H, q = horizontal forces

D, d = diameter and length of the pile

$M_{max}, max\ \sigma$ = maximum bending moment and largest horizontal soil pressure

z_M, z_σ = depth of M_{max} and max σ

$L = \sqrt[4.5]{\frac{E \cdot I \cdot d^{0.5}}{16 \cdot D \cdot k_s}} = \sqrt[4.5]{\frac{1{,}800 kN/cm^2 \cdot 135.2 cm^2 \cdot 340^{0{,}5} cm^{0.5}}{16 \cdot 7.5 cm \cdot 240 \frac{kN}{cm^3}}} = 3.07m$ = “characteristic” pile length

$E = 1{,}800 \frac{kN}{cm^2}$ = cf. 0

$I = 135.2 cm^2$ = cf. 0

$\lambda = \sqrt{\frac{d}{L}} = \sqrt{\frac{3.40m}{3.07m}} = 1.05$ = slenderness ratio

$w =$ dislocation of the pile head

$k_s \approx \frac{E}{D} = \frac{1{,}800\ kN}{7.5\ cm \cdot cm^2} = 240\ \frac{kN}{cm^3}$ = bedding modulus at the pile foot for slender piles

$$\left.\begin{array}{l}\alpha = 0.21 \\ \beta = 2.5 \\ x_M = 0.38 \\ x_\sigma = 0.24\end{array}\right\} \text{tabular values}$$

The horizontal design force resulting from current and wave induced loads is 2 kN. The horizontal design force resulting from wind is 0.04 kN. Combinations of wind, tide and waves during intermediate water levels are not considered due to the overbalancing value of current and wave loads. The horizontal design force results from current and wave induced loads on the wall.

The impact of a floating item will affect several bamboo piles depending on the angle of the impact and the diameter of the floating item (e.g. tree trunk, vessel). It is assumed that the impact force of 45 kN will hit 3 bamboo piles and will be equally distributed over those piles. The horizontal bamboo bars distribute the forces on the surrounding vertical piles (2/3 on the three hit piles, 1/6 each on the neighbouring piles). Nevertheless the impact force on a single hit pile will be 10 kN.

Table 4 summarizes the values of M_{max}, z_M, max σ, and z_σ for the different loading cases according to the equations above.

Table 4: Calculation of M_{max}, z_M, max σ, and z_σ for the different loading cases

	Tide & waves; wind H = 2 kN	Breaking waves H = 0.051 kN	Impact H = 10 kN
M_{max} [kNm]	1.43	0.04	7.14
z_M [m]	1.29	1.29	1.29
max σ [kN/cm²]	$2.2 \cdot 10^{-3}$	$5.7 \cdot 10^{-5}$	0.01
z_σ [m]	0.82	0.82	0.82

The maximum momentum at the elastic clamping due to tidal currents, waves and wind is calculated as 1.43 kNm.

According to Figure 7, the resulting compressive force and drag force on the upper and lower boom of the bamboo is:

$$F = \frac{M}{d} = \frac{1.43\ kNm}{0.075m} = 19.1\ kN$$

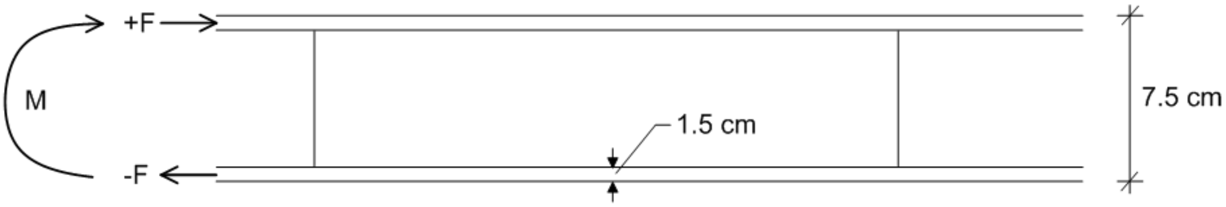


Figure 7: Distribution of the momentum into a force couple

The bending strength is calculated as:

$$\frac{19.1\ kN}{28.27\ cm^2/_2} = 1.4\ \frac{kN}{cm^2} < 7.6\ \frac{kN}{cm^2} \checkmark$$

Therefore, the proof of the bending strength of single bamboo piles due to current- and wave-induced loads and wind loads is given.

The maximum horizontal soil pressure due to tidal currents, waves and wind is $2.2 \cdot 10^{-3}$ kN/cm². The limit value of the jacket friction can be estimated as $2.5 \cdot 10^{-3}$ kN/cm² according to international standards. Therefore the proof of shear failure is given in this loading case.

The connection of the bamboo piles with horizontal bars distributes the forces and increases stability. Thus, the proof of the bamboo fence is fulfilled.

Temporary slamming forces caused by breaking waves may increase the momentum on the bamboo pile for a short period to 0.04 kNm and the maximum horizontal soil pressure to $5.7 \cdot 10^{-5}$ kN/cm².

The resulting compressive force and drag force in the upper and lower boom of the bamboo is:

$$F = \frac{M}{d} = \frac{0.04\ kNm}{0.075m} = 0.54\ kN$$

The bending strength is calculated as:

$$\frac{0.54\ kN}{28.27\ cm^2/_2} = 0.04\ \frac{kN}{cm^2} < 7.6\ \frac{kN}{cm^2} \checkmark$$

Therefore, the proof of the bending strength of single bamboo piles due to forces caused by breaking waves is given.

The limit value of the jacket friction can be estimated as $2.5 \cdot 10^{-3}$ kN/cm² according to international standards. Therefore the proof of shear failure in case of breaking waves is given.

The resulting maximum momentum at the clamping due to an impact is 7.14 kNm and the maximum horizontal soil pressure 0.01 kN/cm².

The resulting compressive force and drag force in the upper and lower boom of the bamboo is:

$$F = \frac{M}{d} = \frac{7.14\ kNm}{0.075m} = 95.2\ kN$$

Bending strength:

$$\frac{95.2\ kN}{28.27\ cm^2/_2} = 6.8\ \frac{kN}{cm^2} > 7.6\ \frac{kN}{cm^2} \checkmark$$

Therefore, the proof of stability of the construction due to an impact of a floating item of 300 kg is given.

The maximum possible impact assuming the boundary conditions mentioned above (and failure of the bamboo piles) is 50.8 kN, which corresponds to the impact of a floating item weighing 338 kg with a velocity of 0.30 m/s.

The limit value of the jacket friction can be estimated as $2.5 \cdot 10^{-3}$ kN/cm² according to international standards. Therefore, the proof of shear failure in the case of an impact on the assumed order of magnitude is not given.

In the case of a larger impact on a single pile, the breakwater will be deformed in the proximate area of the impact due to the exceeded maximum horizontal soil pressure. If the floating item hits a larger area of the breakwater, the impact forces will be distributed over more bamboo piles and the construction will be stable.

In consideration of risk management, it is not advisable to strengthen the entire construction due to the relatively low effort to maintain deformed parts of the breakwater in the case of a significant impact. Reinforcement of the structure would increase costs significantly, while the risk for damage due to an impact or vandalism is very low.

The calculations above assume an elastic clamping of the bamboo piles into the ground. In the case of a severe impact, the embedment of affected bamboo piles will be relocated due to shear failure. It is most likely that the affected piles will not break even in the case of a strong-

er impact and can be easily returned to the original position. Even in the case of a major impact on a single pile resulting in the failure of that pile, it can be exchanged quickly and easily.

Estimations concerning geotechnical parameters are especially prone to large uncertainties. The calculations above are based on conservative assumptions. In natural settings, it is most likely that the limit value of the jacket friction will be significantly larger. The effective values can only be determined with on-site tests and measurements. For this reason, the construction supervision and the tensile tests are of high importance.

7 PLANS

7.1 Site maps and description

Detailed planning has been carried out based on the preliminary design. Attachment 1 shows the site map of the construction including the positions of the breakwater and the fences, the dimensions and the distances. Attachment 2 shows the site map without the background, and Attachment 3 shows the locations of the control points. Furthermore, the positions of the sections are marked on the site map.

In the eastern part of the focus area at Vinh Tan, a bamboo breakwater with a length of 100 m will be constructed parallel to the shoreline. The heading of the breakwaters' axis from west to east is 71.5°. The distance from the revetment at the dyke is 113.08 m, which corresponds with the distance to the idealized shoreline in the numerical model of 50 m. The basis for the site map is a GPS survey from 26.01.2011.

In the lee area of the breakwater (relative to the main wave direction) bamboo fences will be constructed. The heading of the cross-shore fences is 161°; the heading of the longshore fences is 71°. The cross-shore fences start at the revetment of the dyke and form three main fields. The connection to the existing flood plain west of the focus area is done with a fourth smaller field. The area east of the fences lies in the influence of the accretion area of the breakwater. The four main cross-shore bamboo fences have a length between 50.00 m and 56.70 m. The short fence has a length of 14.20 m. The width of the main fields is 50.00 m; the width of the smaller field in the west is 40.00 m.

The longshore fences are constructed at the tip of the cross-shore fences. They have a length of 30.00 m in the main fields; the cross-shore fence is attached in the middle of the longshore fence. The length of the western longshore fence is 20.00 m. The opening width of the main fields is 20.00 m; the opening width of the small field is 15.00 m.

On the site map, 13 GPS points are marked, which are used for the placement of the construction.

7.2 Front views, cross sections and top views

Front views, cross-sections and top views of the bamboo breakwater and the bamboo fences as well as the connections can be found in Attachments 4 to 12.

7.3 Details

Additional details of the constructions can be found in Attachments 13 and 14.

In addition, Figure 8 shows a lashed joint, the most frequently used method of joining bamboo piles. The tie material is also organic and thus ensures optimal compatibility between the elements of the structure.

Figure 8: Joint made with rattan strips (DUNKELBERG, 2000)

8 CONSTRUCTION PROGRESS

8.1 Preparation and site facilities

Before construction starts, the GPS positions on the crest of the dyke, on the revetment and at the construction location have to be located and marked. Taking into account the accuracy of the available data, a horizontal execution accuracy of approximately 1 m is proposed. Therefore, a standard GPS receiver may be used. To control the positions the headings from one position to another and the headings of the breakwater and the fences must be controlled by compass. The dimensions and distances must be controlled by chain or laser measurement.

Due to morphologic changes in the months after the last survey, the elevation of the mud in the area of the breakwater and the fences has to be determined to calculate the clear height of the vertical piles above the ground.

No area-consuming site facilities are needed. A place for the storage of the bamboo, the brushwood, the connection material and the needed tools for the installation has to be installed behind the dyke, for the construction phase of the bamboo fences. For the construction of the breakwater, the storage of materials on a pontoon or on a vessel is recommended.

The brushwood has to be roped up into bundles before being brought to the installation location.

8.2 Installation

The cross-shore fences near the dyke will mainly be installed manually. The breakwater and the longshore fences should be installed by means of technical devices from a vessel. Therefore, different installation methods are necessary.

If the piles are installed manually, a pile hole should be prepared using a sharpened round timber with a handle bar (cf. Figure 9). The timber is pushed into the mud with a stirring movement to pre-drill a hole.

Then, if available, the piles can be installed with a pile-driving machine or pressed into the mud and sand with a dredger bucket (Figure 10). Alternatively a head ram can be used that is handled by two men. It is also possible to use two men’s weight to press the piles into the soil with a rope being used to exert force on the pile. If a pile driving machine is used, the head of the pile has to be protected.

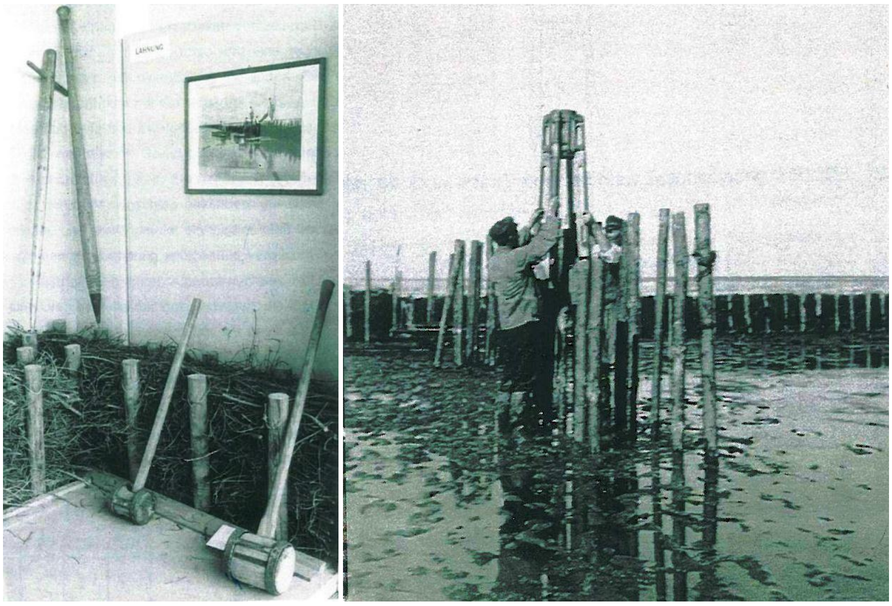


Figure 9: Sharpened round timber with a handle bar for the preparation of the installation (left), head ram for the installation of the vertical piles

Figure 10: Installation of vertical piles using a pile-driving machine or a dredger bucket

The best way to install the bamboo piles of the breakwater and the longshore fences is to use water pressure. Therefore a vessel with electricity, a pump and water is needed. The installation has to be done during calm weather conditions and when there are adequate water levels to move the vessel along the breakwater or fence. An immersion pump with a delivery height of 35 m or more should be used. A hose is attached to the pump; the end section of the hose is a hollow steel lance. One man holds the pole while another worker controls the lance and leads it parallel to the bamboo pile. Due to liquefaction of the surrounding soil at the head of

the lance, the bamboo pile can be installed into the soil with little pressure. Then the lance can be pulled out. The lance should be as long as the desired anchoring depth of the pole. The connection of the hose to the lance can be done using commercial hose connections and a winding on the lance. A diminution at the head of the lance is advisable to increase pressure at the head. A movement of the lance (up and down) increases the grade of liquefaction and makes it easier to plunge the pile.

Figure 11: Steel lance for the installation of the vertical piles with water pressure

If the weather does not allow for the described installation, or if a suitable vessel or equipment is not available, the piles of the breakwater and the longshore fences can be installed in the same way as the cross-shore fences near the dyke.

After installation of the vertical bamboo piles, the horizontal bars are attached to the vertical piles with bamboo strips or jute rope. For both materials, there are different values for tensile strength. An average value 7 kN/cm^2 can be assumed. For a rope with a diameter of 1 cm, this results in a tensile strength of approximately 5.5 kN. The real tensile strength of the connection material has to be assessed with several on-site tests.

After fitting the brushwood bundles between the bamboo piles and compressing them by man weight, the piles are connected crosswise with bamboo strips or jute rope. That results in a mutual reinforcement and avoids leafing of the bundles. The compressing must not be done by means of machines, e.g. dredger bucket. The smaller branches of the bundles, which are im-

portant for the gearing, could be broken. Therefore, the bundles should be handled with care and by hand as much as possible. Due to their permeability, elastic force and very fine branches, the bundles dissipate the wave forces very well and reduce the currents significantly. The compression and crosswise connection of the bundles has to be done for each layer of bundles. Depending on the compressibility of the brushwood, an average 4 layers of bundles will be installed.

The crest of the breakwater and the longshore fences is at the same elevation as the daily mean high water level. At the connection to the longshore fences, the cross-shore elements have the same elevation. Due to the dyke, the elevation of the crest decreases so that a plain connection to the revetment of the dyke can be realized. This means a gradient of the cross-shore fences of approximately 1 %. At the dyke, a connection of the cross-shore fences to the piles of the revetment is done.

The bundles should be approximately 2.00 m long with a diameter of maximum 50 cm. The branches should be fresh and not brashly. The ends of the trunks should not be thicker than 2.50 cm. The branches should be slender, straight and densely grown.

8.3 Construction sequence

First the construction of the breakwater will be done from west to east. Afterwards the bamboo fences will be constructed beginning with the westernmost main cross-shore fence (length 50 m) followed by the accordant longshore part. Then the three T-shaped fences to the east will be constructed in accordance with the described plans. The last structures to be installed will be the westernmost fences (length of cross-shore fence, 14.20 m).

8.4 Drainage system

An artificial drainage system in the fields accelerates the sedimentation rate. The drainage system is a network of ditches, which improves the seaward drainage of the areas near the dyke. Furthermore, the network controls the inflowing water and its sediment load. These sediments are deposited in the ditches. During the maintenance of the ditches, the deposited material will be distributed in the fields and increase the elevation there. The ditches are created either with a dredger or manually.

Figure 12 shows the network in the three main fields. Due to its size, the smaller field in the west of the focus area does not need a drainage system. Figure 13 shows the cross-sections of the main and the minor ditches.

The installation and maintenance of the drainage system costs money. The creation of a drainage system depends on the morphologic situation at the time of construction. If the breakwater and the fences are installed during a period of increased sedimentation, the drainage system can be neglected. If the installation is done during a period of increased erosion, the drainage system should be applied.

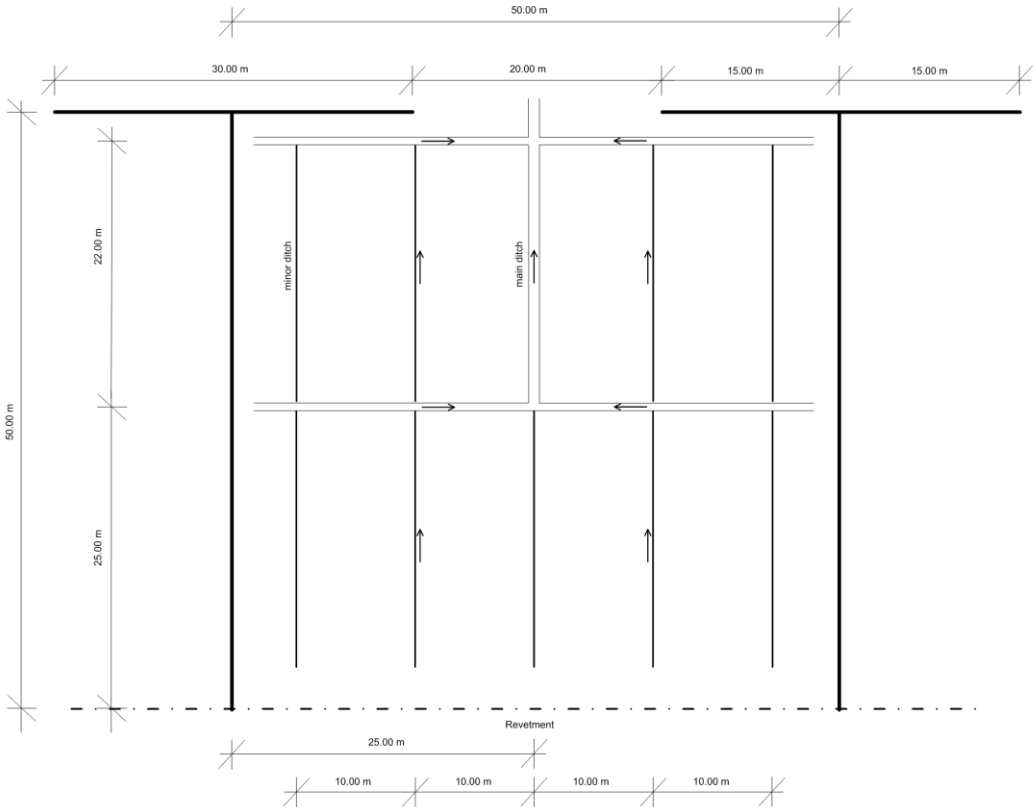


Figure 12: Drainage network in a main field

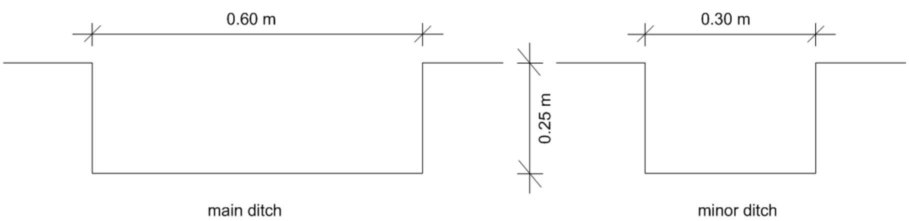


Figure 13: Cross-section of main and minor ditches of the drainage system

9 AMOUNT OF MATERIAL

Table 5 estimates the amount of materials needed for the construction of the bamboo breakwater and the bamboo fences. Each bamboo pile of the longshore elements has a diameter of 0.08 m. Each bamboo pile of the cross-shore elements has a diameter of 0.06 m.

Table 5: Estimated amount of material for the breakwater and the bamboo fence

	Bamboo breakwater	Bamboo fence (longshore)	Bamboo fence (cross-shore)
Vertical piles per metre [-/m]	12	12	12
Horizontal piles per metre [-/m]	8/9	8/9	8/9
Length [m]	100	140	229
Number of piles [-]	1,289	1,805	2,952

If 6 vertical piles are installed next to each other in each row with a distance of 0.10 m, this equals a distance of 1.08 m (0.96 m for cross-shore fences). Due to tolerances in the diameter and the installation, e.g. inclination, the value of 6 piles is considered to cover a computational distance of 1 m. For each row, two horizontal piles are installed at different heights. The overlap of two adjacent horizontal piles is assumed to be 0.35 m. The calculated usable length of a horizontal pile is approximately 4.50 m. Thus, for one metre of bamboo breakwater or bamboo fence, four times 2/9 of a bamboo pile is required for the horizontal bars. A total number of 6,046 bamboo piles are required to construct the breakwater and the bamboo fences; 2,952 bamboo piles with the diameter of 0.06 m, 3094 bamboo piles with the diameter of 0.08 m.

Additionally, the costs for the connection material have to be considered. For the connections, bamboo strips or jute ropes are used. There are 24 connections per metre of the vertical piles and the horizontal bars. For each connection, a length of 3 m is estimated. With a total length of the breakwater and the fences equalling 469 m, a total of 33,768 m of connection material is needed.

For the connection of the bundles to the vertical piles, an additional length of approximately 18,760 m of connection material is required, assuming 4 bundles on top of each other and a required length of 10 m connection material per metre of breakwater or fence.

With the length of a bundle of 2.00 m and an average of 4 bundles on top of each other, approximately 940 bundles are needed. The brushwood should be bonded at three positions on each bundle, which results in approximately 15 m rope per bundle. A total length of 14,100 m rope is also required for the bundles.

10 CONSTRUCTION SUPERVISION

A detailed documentation and monitoring of the construction phase is essential to gain information for future construction.

The construction supervision must include:

- Visual material control of the bamboo piles, the brushwood and the connection material including photo documentation
- Random measurements of the length and diameter of the bamboo piles (approximately every 20th pile) including documentation and analysis
- Random control of the bundles (length, diameter, quality, connections) including documentation; measurement of approx. every 30th bundle
- Random control of the connection material; approximately 30 breaking tests
- Documentation of the installation method of the vertical piles and additional information, e.g. the number of hits
- Documentation of the thickness of the mud layer
- Control and documentation of the depth of embedment
- Control and documentation of the distances between the vertical piles
- Control and documentation of the inclination of the piles
- Visual control of the connections (vertical piles – horizontal bars, vertical piles - bundles) including photo documentation
- Random tensile tests of the vertical bamboo piles; approx. 20 to 30 tests depending on the soil characteristics

10.1 Tensile tests

Due to uncertainties in the bedding modulus, the maximum horizontal load of the vertical piles and the breakwater/bamboo fences respectively can only be assessed by means of existing calculation methods (cf. Chapter 6.2). To get resilient values for the maximum horizontal forces and information about the failure mechanism (soil or bamboo), tensile tests have to be carried out. That will offer valuable information for further installation of bamboo constructions.

It is recommended that between 20 and 30 tensile tests be carried out during the installation. The selection depends on the soil characteristics and the tests should be carried out in different locations to get a good sample of the installation.

After a regular installation of a vertical bamboo pile, it is stressed until it fails. Therefore, an abutment is needed. That can be a vessel (if available) or consist of embedded vertical piles that have a higher maximum horizontal resistibility, e.g. a group of three to four piles (cf. Figure 14). Then, a tension belt is clamped between the abutment and the tested pile and the horizontal force is increased with a belt spanner (cf. Figure 15, left). The belt is attached to the tested pile at the head of that pile (~ 30 cm beneath the top) and running parallel to the ground. To avoid the tension belt slipping from the pile, the belt should be fixed with some rope. The accordant force is measured with a force meter. Therefore, it is sufficient to record just the breaking load and not the entire loading path. The tests and the type of failure have to be documented; the breaking loads have to be recorded. Due to the characteristics of the bamboo, a sudden failure of the material causing danger to the workers can be excluded. The same applies for the case of failure of the soil.

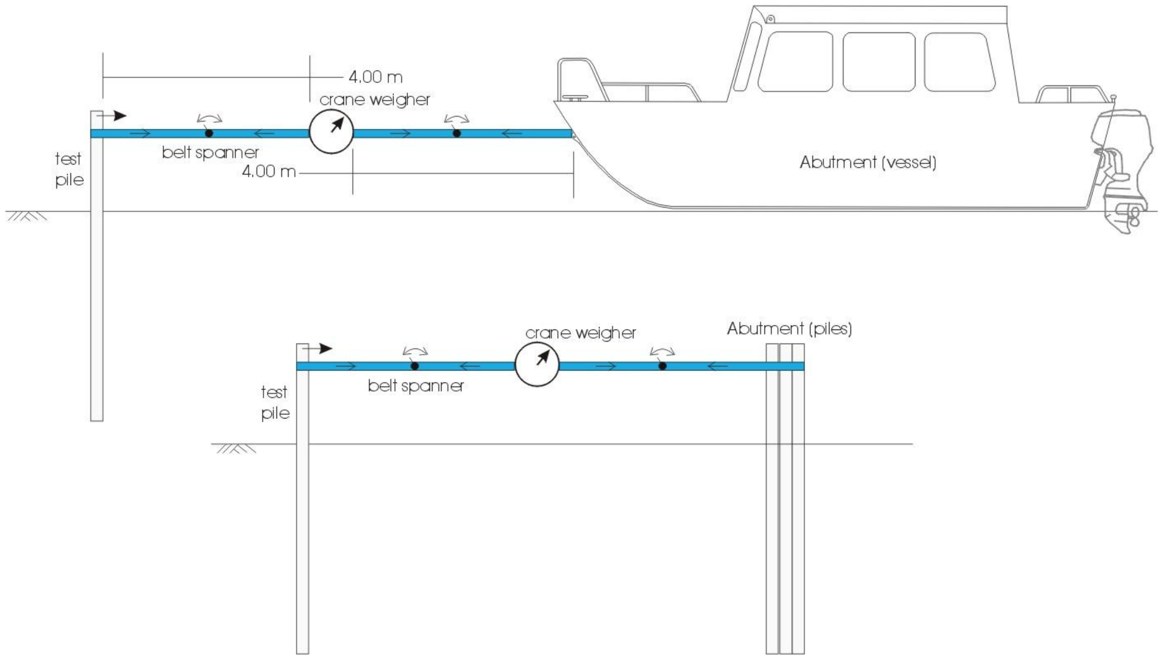


Figure 14: Setup of the tensile tests (2 options of abutment)

A standard crane weigher can be used as a force meter (cf. Figure 15, right). The maximum load should be 600 kg with a resolution of 0.2 kg. The tension belt should have a width of 50 mm, which results in a tensile strength of 40 kN. The length of the tension belt should be 10 m.

Figure 15: Tension belt including belt spanner (left), crane weigher (right)

It is strictly recommended to carry out two or three tensile tests before the construction, to test and optimize the installation method, to assess the quality of embedment and – if necessary – to be able to react to changed circumstances, e.g. increased or decrease elevation of the mud level. Depending on the actual soil characteristics a reduction of the depth of embedment may be possible.

11 OUTLOOK

The construction of the bamboo breakwater and the bamboo fences at Vinh Tan has to be considered as a pilot project. Detailed documentation and broad monitoring is essential to gain knowledge for future applications.

In the context of the monitoring program, the development of the shoreline, the floodplains and the tidal flats between the dyke and the bamboo structures must be recorded. Due to the shallow water depths there, soundings by boat are not sufficient. The bottom elevation should be measured manually using Differential GPS in a 10 m grid. After the first measurement just before the construction, monthly measurements should initially be carried out; after six months this interval should be reduced to quarterly measurements.

To assess the effect of the structures compared to other locations where no measures were applied, one other location must also be monitored regularly parallel to the focus area. This will help to identify morphodynamic processes that are related to superior trends.

The change of the grain size distribution and the consolidation grade in the area surrounding of the measurements should be analyzed by means of quarterly sediment sampling in a 25 m grid.

Measurements of suspended sediment concentrations, waves and currents should be carried out through campaigns covering different seasons starting immediately after the construction and continued semi-yearly.

Monthly georeferenced photos should be taken in the focus area. The camera position on the dyke, the height, the angle and the direction of every photo must be the same to observe the development of the floodplains.

Aerial views – or better – orthophotos in an annual cycle are helpful to follow and quantify the morphologic development.

Based on monitoring, the appropriate time for planting mangroves on the tidal flats can be identified.

All recorded data should be analyzed to provide detailed verification of the success of the measures.

12 REFERENCES

AICHER, S. (2000): Untersuchungen zur Tragfähigkeit der Bambusart "Guadua Angustfolia". Otto Graf Institut, Stuttgart

ALBERS, T., LIEBERMAN, N. VON (2011): Management of Natural Resources in the Coastal Zone of Soc Trang Province – Current and Erosion Modelling Survey. Final Report. Published by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

ARZ, P., SCHMIDT, H.G., SEITZ, J., SEMPRICH, S. (1991): Grundbau – Sonderdruck aus dem Betonkalender 1991. Grund- und Pfahlbau GmbH, Frankfurt am Main

ATROPS, J. L. (1969): Elastizität und Festigkeit von Bambusrohren. In: Der Bauingenieur 44, Heft 6

DUNKELBERG, K. (2000): Bambus als Baustoff. In: Mitteilungen des Instituts für leichte Flächentragwerke IL Nr. 31, 4. Unveränderte Auflage, Karl Krämer Verlag, Stuttgart

EAK (2002): Empfehlungen des Ausschusses für Küstenschutzwerke – Empfehlungen für Küstenschutzwerke. In: Kuratorium für Forschung im Küsteningenieurwesen (Hrsg.): Die Küste, Heft 65. Heide in Holstein : Boyens, Germany

HALIDE, H., BRINKMANN, R., RIDD, P. (2004): Designing bamboo wave attenuators for mangrove plantations. In: Indian Journal of Marine Science, Vol. 33(3), pp. 220-225

JANSSEN, J. A. (1981): Bamboo in Building Structures. Dissertatie Drukkerij Wibro, Helmond, The Netherlands

JANSSEN, J. A. (1990): Bamboo Research at the Eindhoven University of Technology. Eindhoven, The Netherlands

LINDEMANN, J., STEFFENS, K. (2000): Der Bambus-Pavillion zur EXPO 2000 in Hannover. In: Bautechnik 77, Heft 6+7, Verlag Ernst & Sohn

von Lieberman GmbH
>> Bauen und Umwelt <<

Dipl.-Ing. Thorsten Albers
(Expert River and Coastal Engineering)

Deutscher Akkreditierungs Rat
DAR
DAP-PL-3797.00

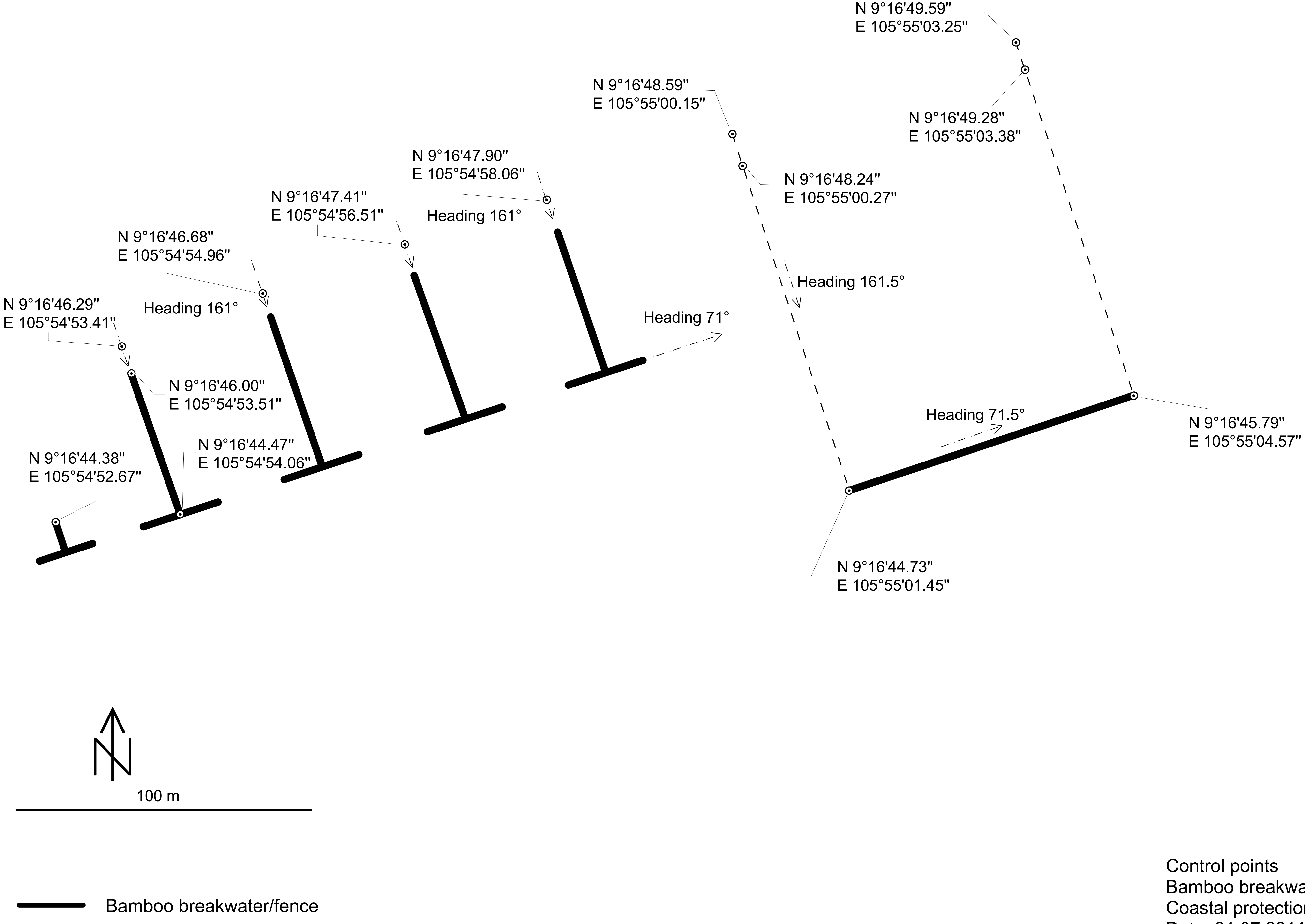
Die Akkreditierung gilt für die in der Urkunde aufgeführten Verfahren.

Attachments

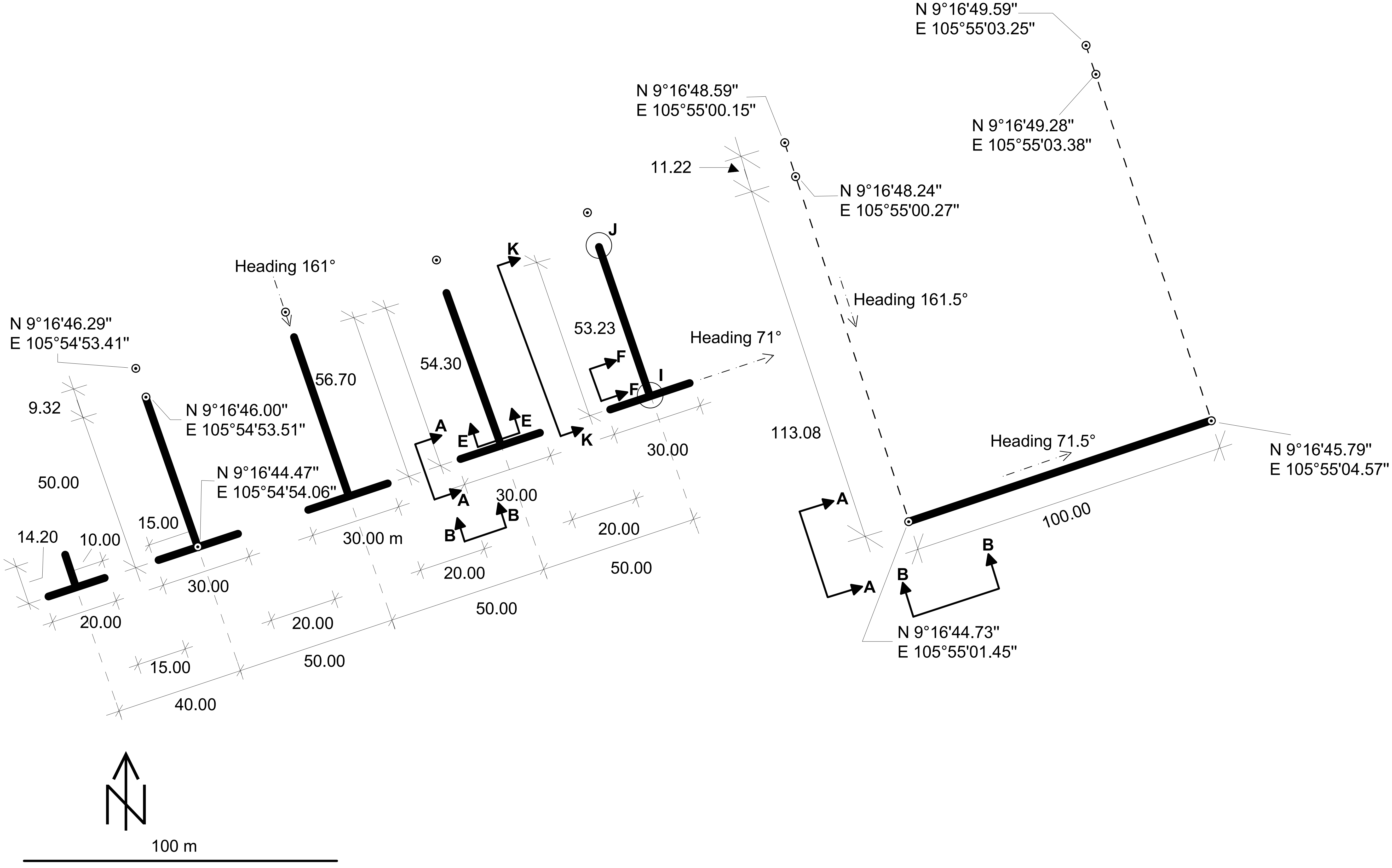
Shoreline 26.01.2011 (GPS survey)

Bamboo breakwater/fence

Site map
Bamboo breakwater and fences
Coastal protection Vinh Tan
Date: 01.07.2011
Dipl.-Ing. Thorsten Albers



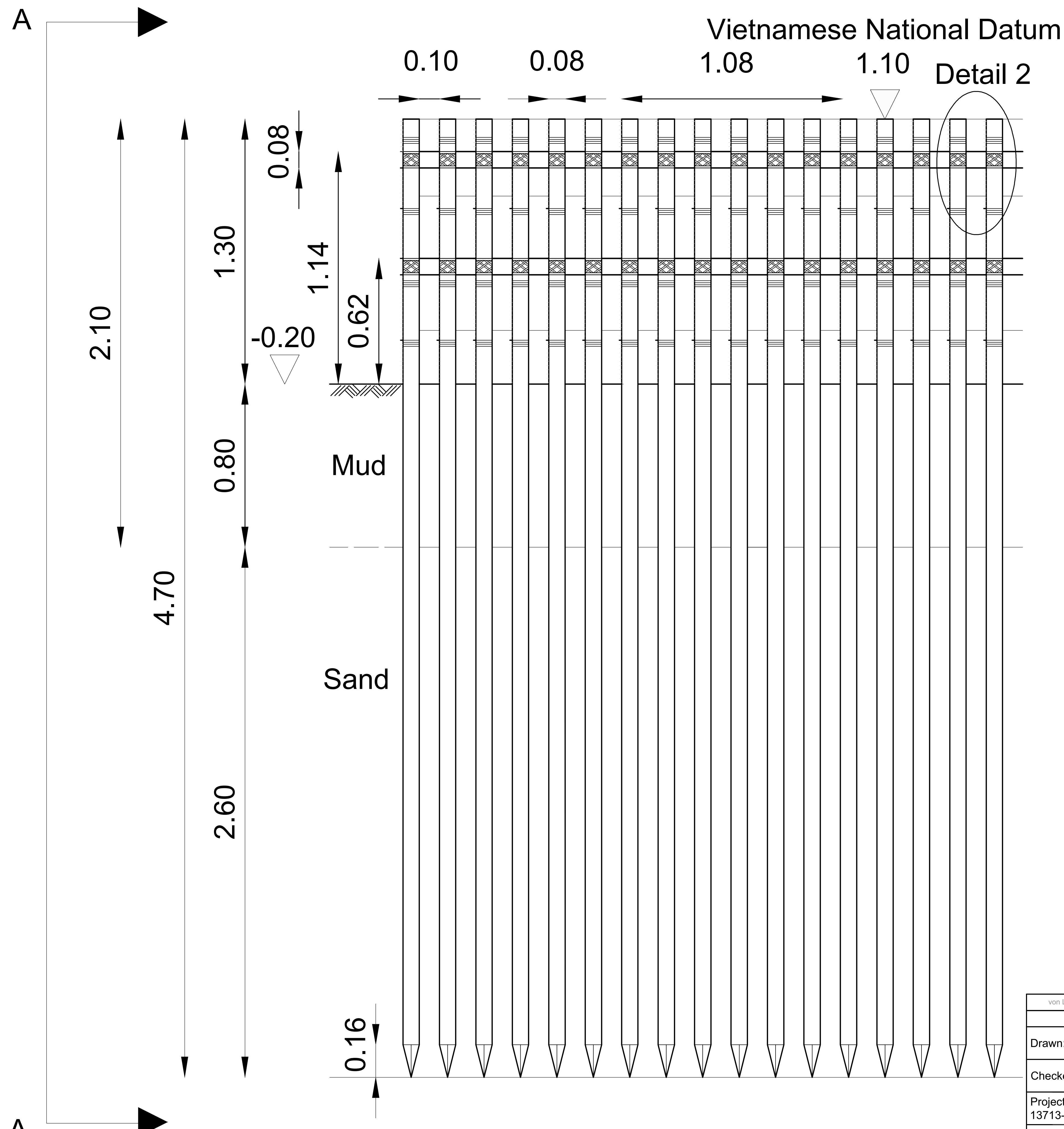
Control points
Bamboo breakwater and fences
Coastal protection Vinh Tan
Date: 01.07.2011
Dipl.-Ing. Thorsten Albers



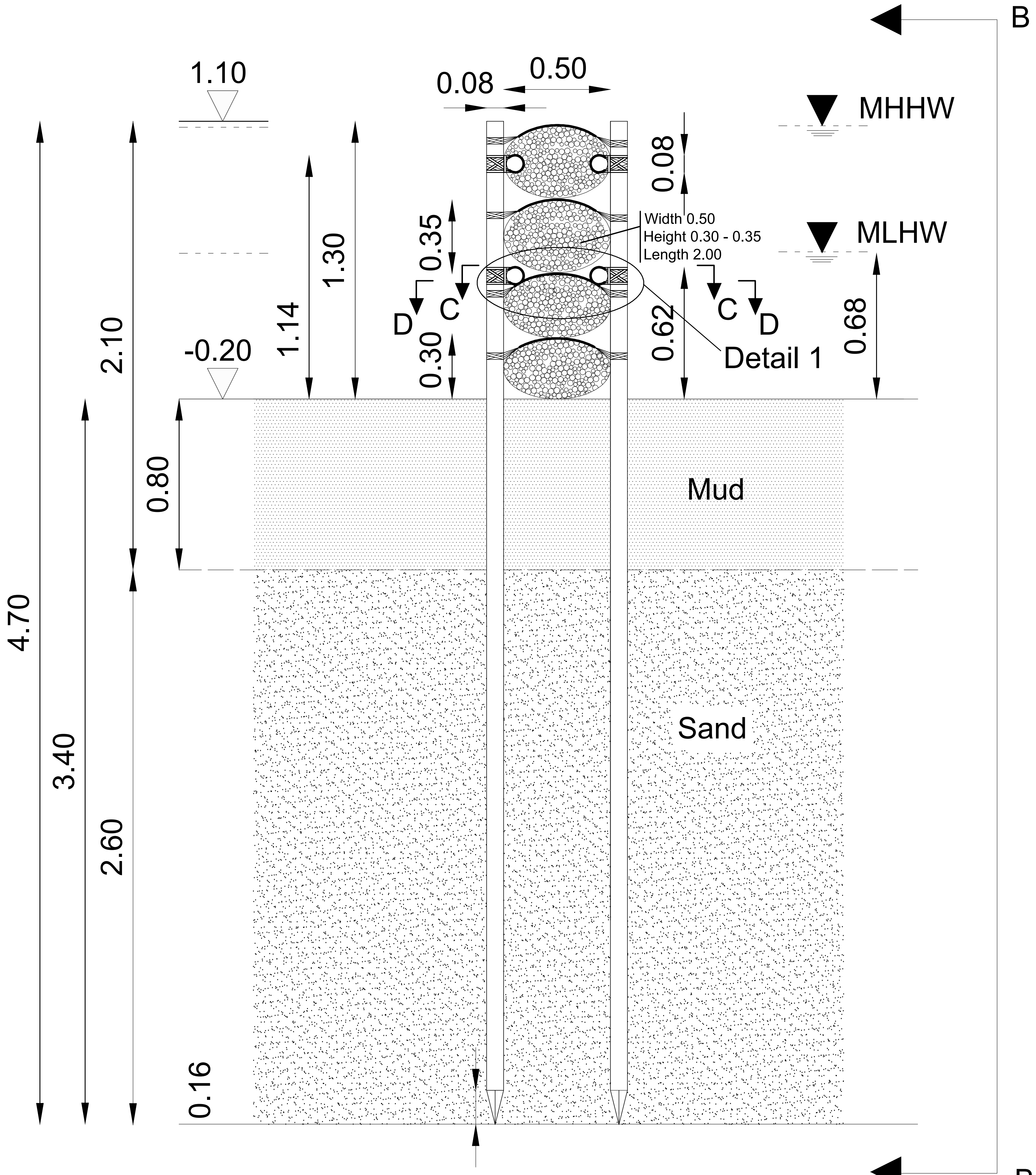
Shoreline 26.01.2011 (GPS survey)

Bamboo breakwater/fence

Site map (without background)
Bamboo breakwater and fences
Coastal protection Vinh Tan
Date: 01.07.2011
Dipl.-Ing. Thorsten Albers



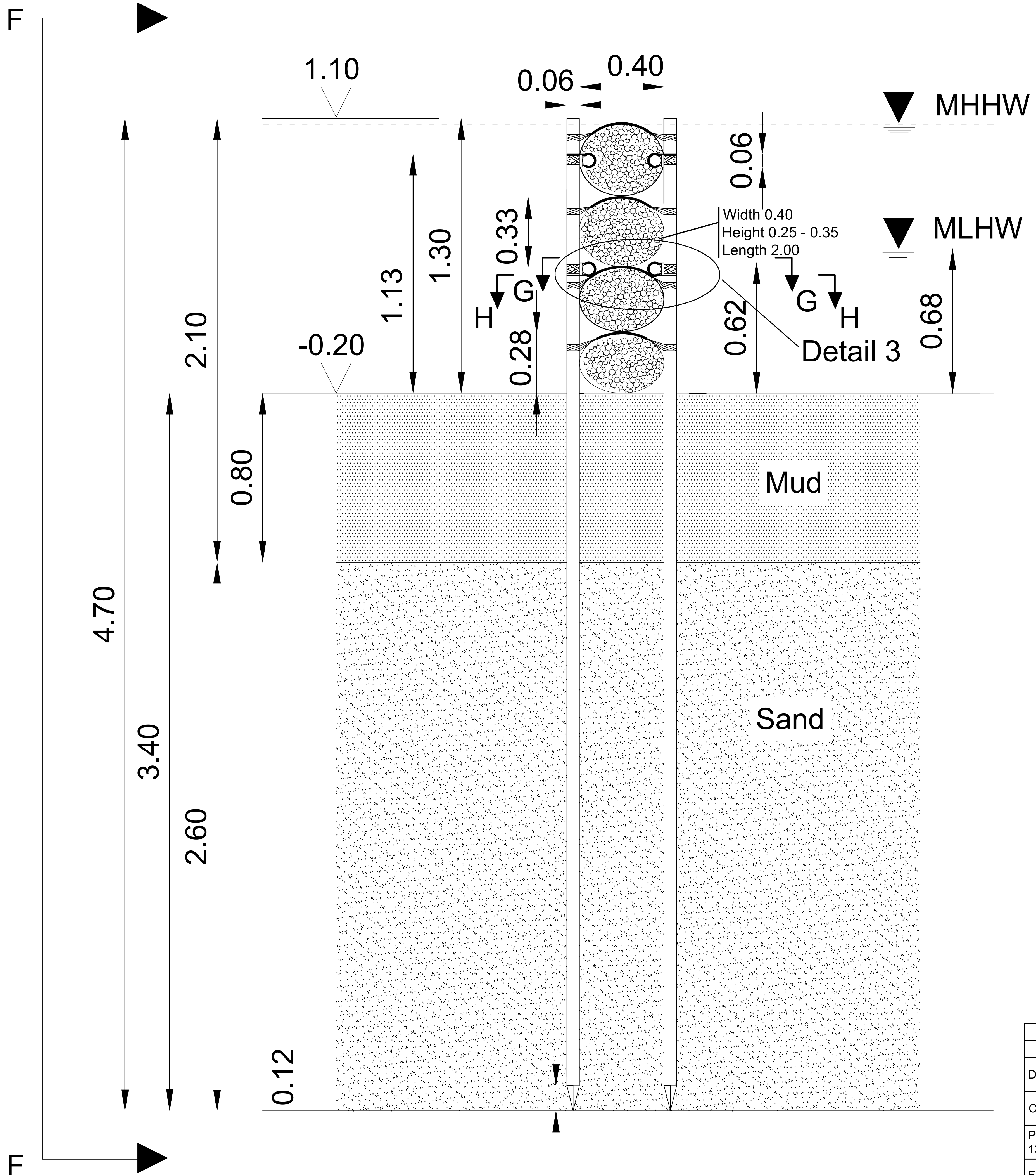
von Lieberman GmbH does not assume liability for mistakes in this plan.				Ingenieurgesellschaft von Lieberman » Bauen und Umwelt «
	Name	Date	Client:	
Drawn:	T. Albers	01.08.2011	GIZ Soc Trang	
Checked:			Content:	
Project no.: 13713-01	Scale: 1:20	Attachment: 5	Bamboo breakwater / longshore fence Section B-B	von Lieberman GmbH Ruhrstr. 57, 22761 Hamburg Tel.: 040 / 500 99 3 -0 Fax.: 040 / 500 99 3 -33
File: bambus_110330.dwg				



	Name	Date	Client:
Drawn:	T. Albers	01.08.2011	GIZ Soc Trang
Checked:			Content:
Project no.: 13713-01	Scale: 1:20	Attachment: 4	Bamboo breakwater / longshore fence Section A-A
File: bambus_110330.dwg			

Ingenieurgesellschaft
von Lieberman
» Bauen und Umwelt «

von Lieberman GmbH
Ruhrstr. 57, 22761 Hamburg
Tel.: 040 / 500 99 3 -0
Fax.: 040 / 500 99 3 -33

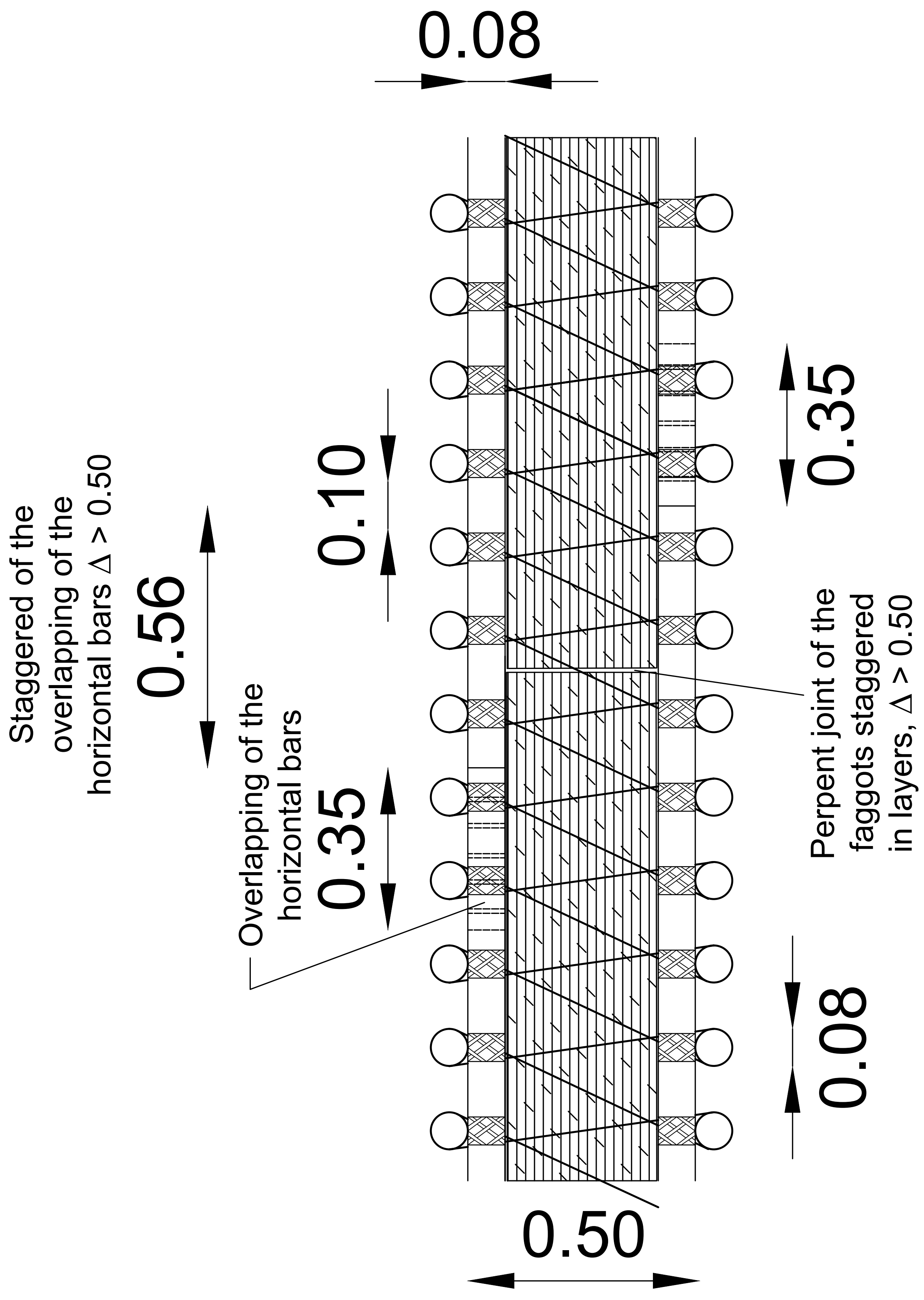


	Name	Date	Client:
Drawn:	T. Albers	01.08.2011	GIZ Soc Trang
Checked:			Content:
Project no.: 13713-01	Scale: 1:20	Attachment: 7	Bamboo fence cross-shore Section E-E
File: bambus_110330.dwg			

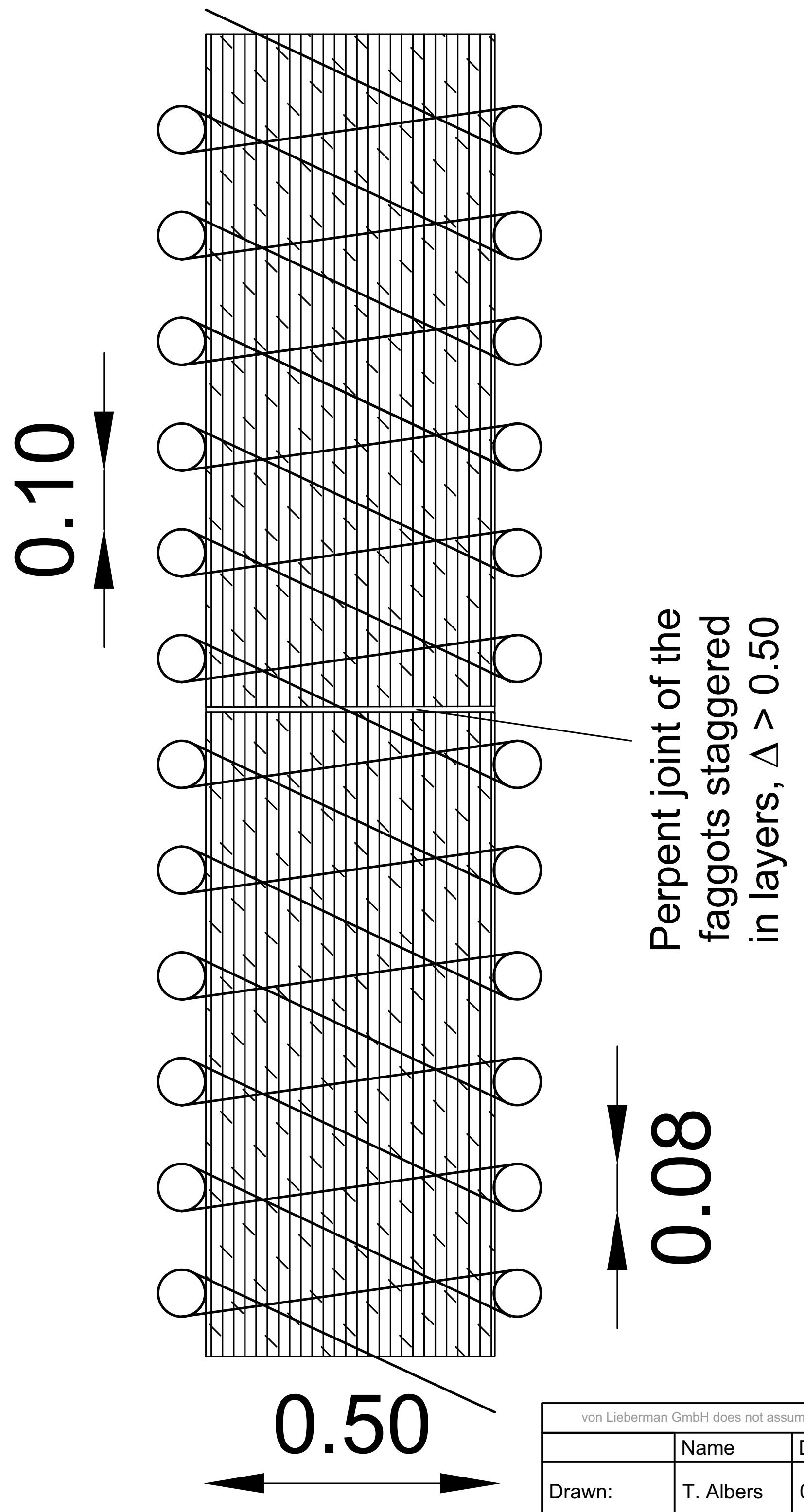
Ingenieurgesellschaft von Lieberman
» Bauen und Umwelt «

von Lieberman GmbH
Ruhrstr. 57, 22761 Hamburg
Tel.: 040 / 500 99 3 -0
Fax.: 040 / 500 99 3 -33

Section C-C



Section D-D

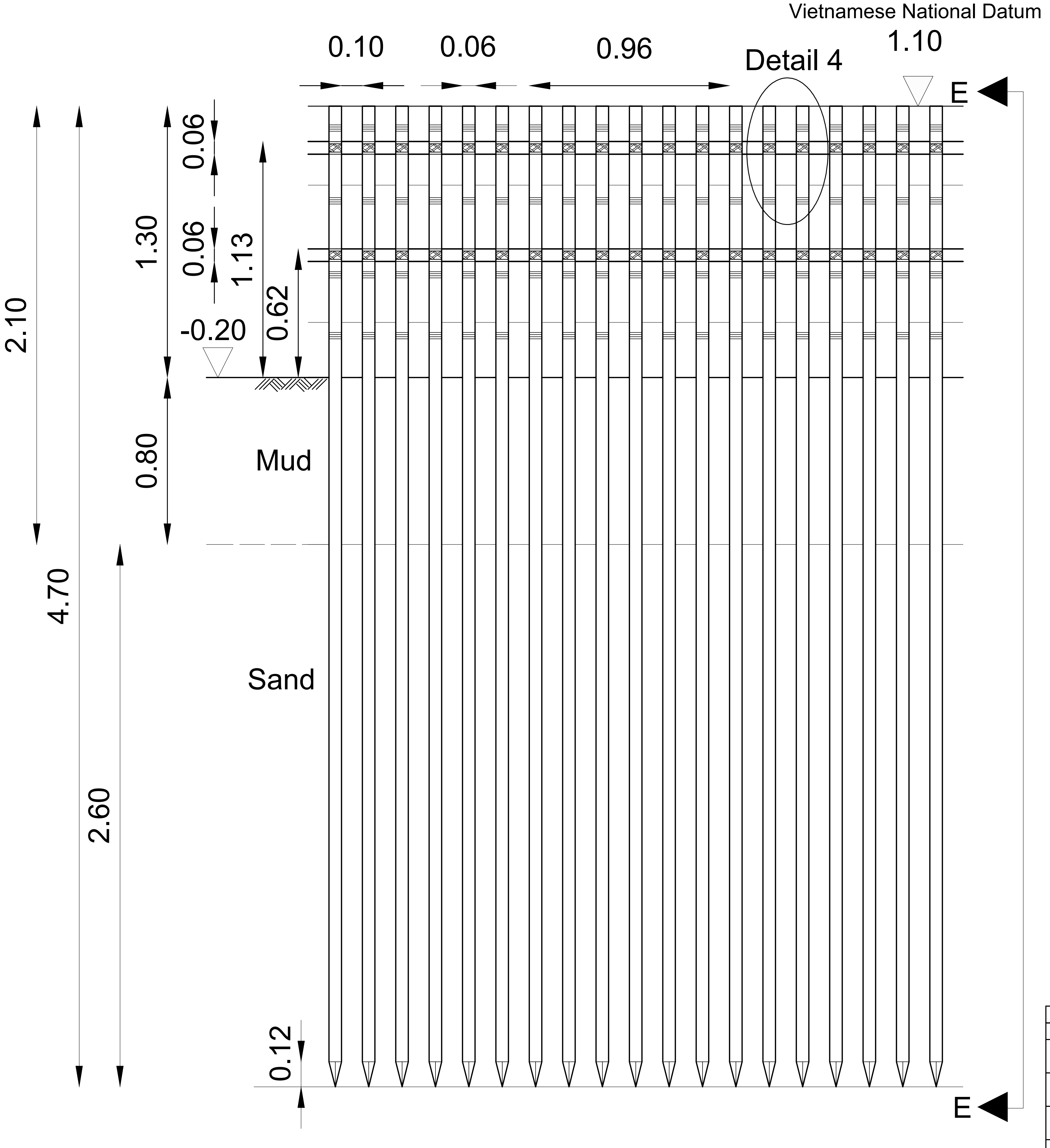


von Lieberman GmbH does not assume liability for mistakes in this plan.

	Name	Date	Client:
Drawn:	T. Albers	02.08.2011	GIZ Soc Trang
Checked:			Content:
Project no.: 13713-01	Scale: 1:12.5	Attachment: 6	Bamboo breakwater / longshore fence Section C-C and D-D
File: bambus_110330.dwg			

Ingenieurgesellschaft
von Lieberman
» Bauen und Umwelt «

von Lieberman GmbH
Ruhrstr. 57, 22761 Hamburg
Tel.: 040 / 500 99 3 -0
Fax.: 040 / 500 99 3 -33



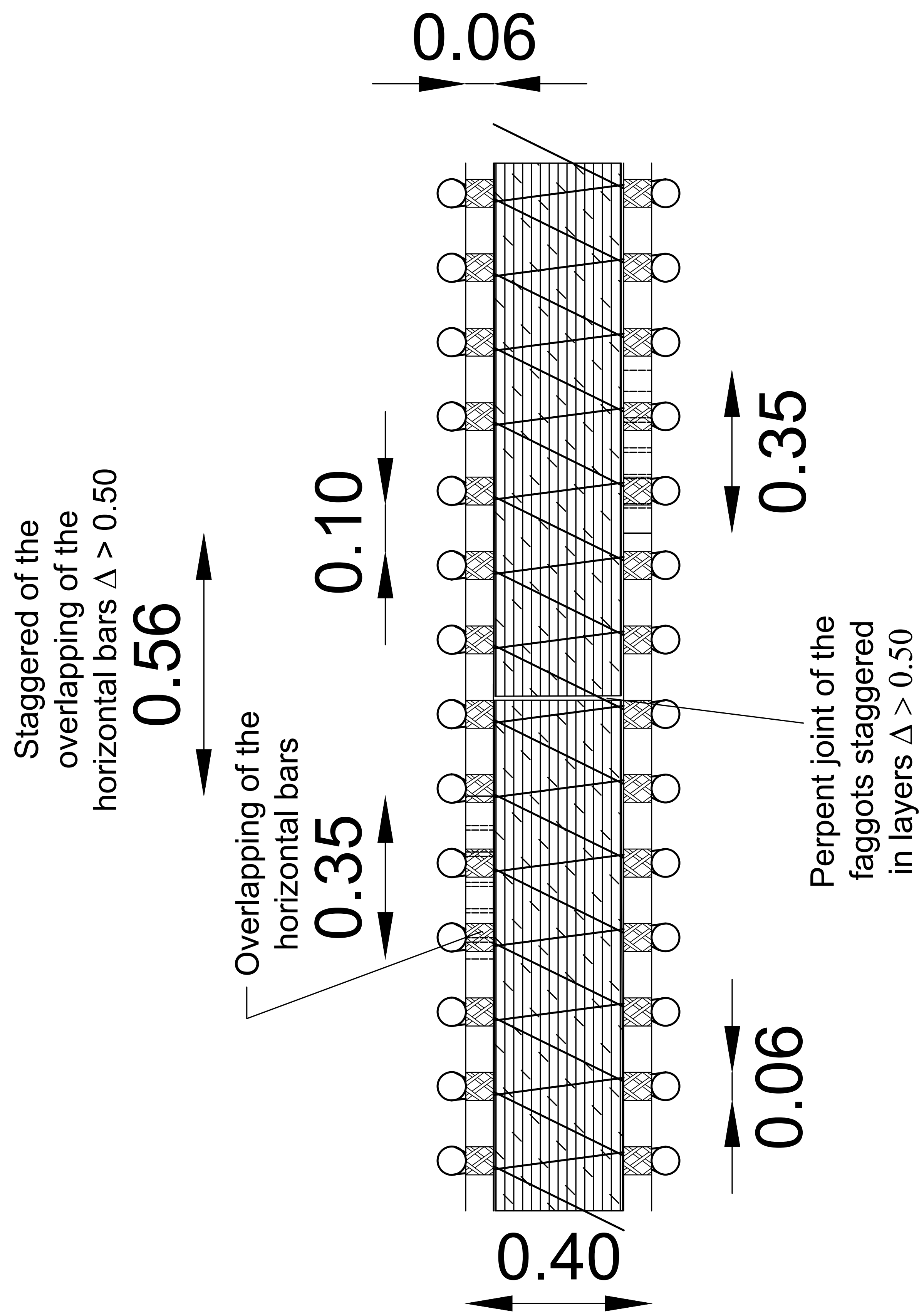
von Lieberman GmbH does not assume liability for mistakes in this plan.

	Name	Date	Client:
Drawn:	T. Albers	01.08.2011	GIZ Soc Trang
Checked:			Content:
Project no.: 13713-01	Scale: 1:20	Attachment: 8	Bamboo fence cross-shore Section F-F
File: bambus_110330.dwg			

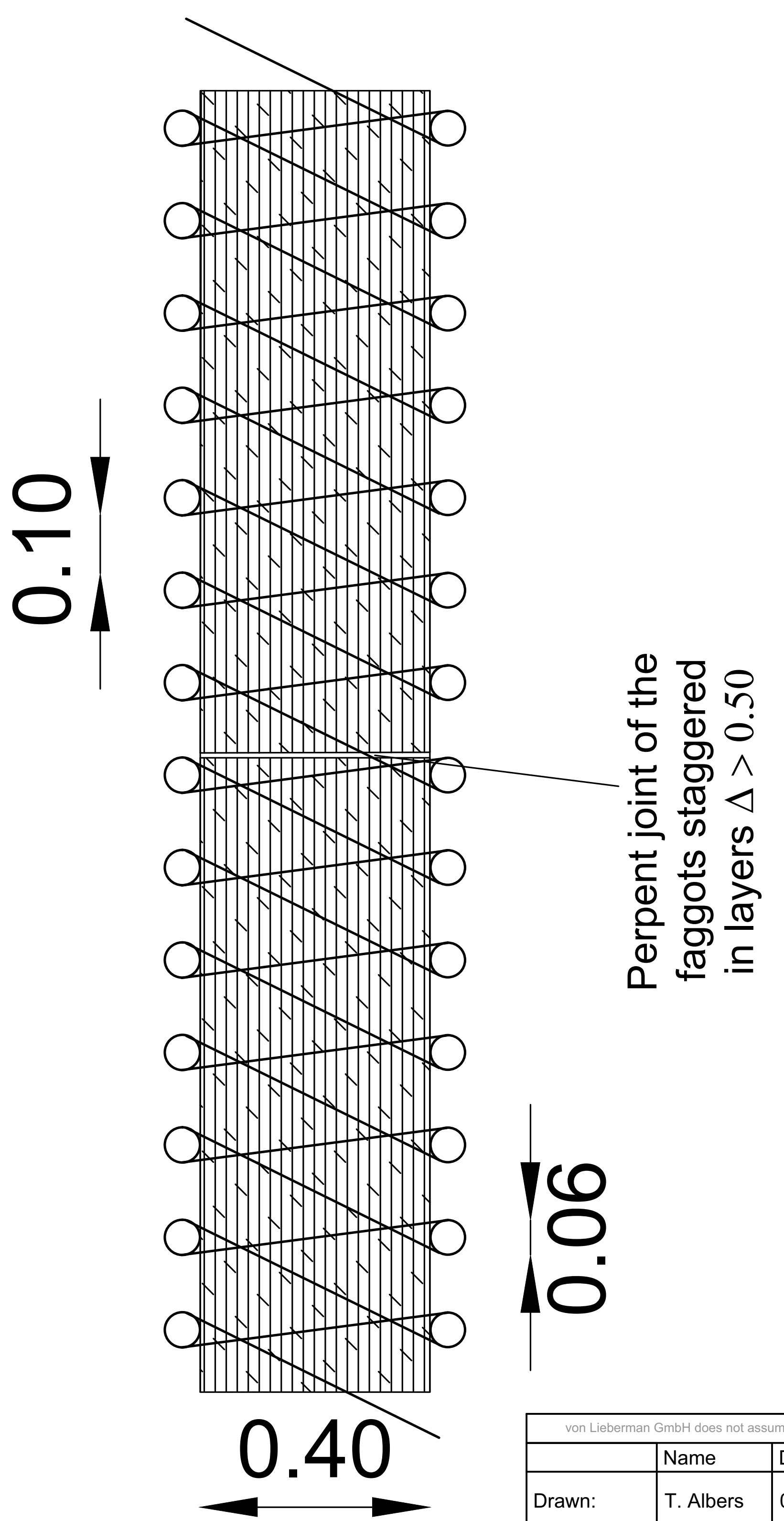
Ingenieurgesellschaft
von Lieberman
» Bauen und Umwelt «

von Lieberman GmbH
Ruhrstr. 57, 22761 Hamburg
Tel.: 040 / 500 99 3 -0
Fax.: 040 / 500 99 3 -33

Section G-G



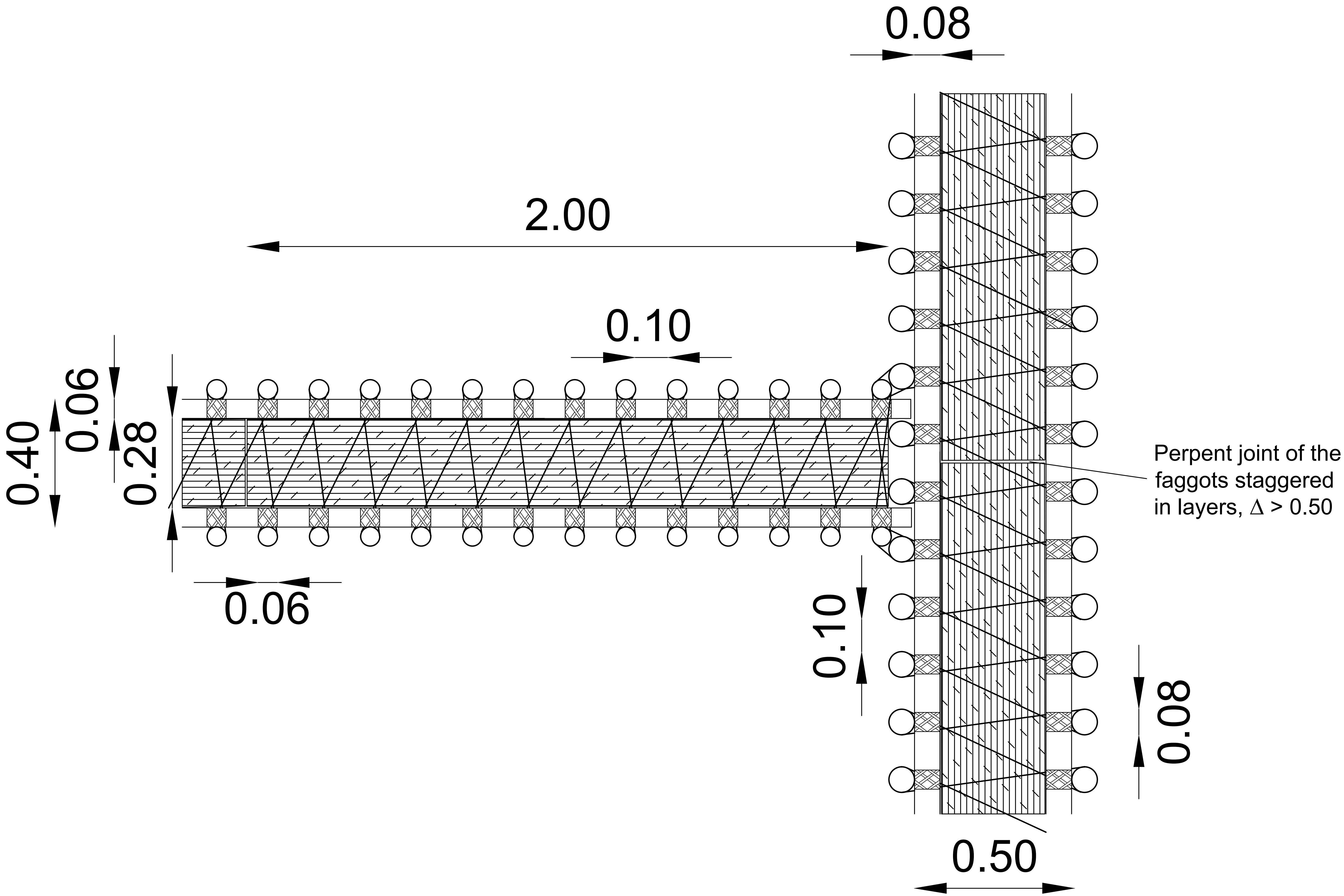
Section H-H



	Name	Date	Client:
Drawn:	T. Albers	02.08.2011	GIZ Soc Trang
Checked:			Content:
Project no.: 13713-01	Scale: 1:12.5	Attachment: 9	Bamboo fence cross-shore Section G-G and H-H
File: bambus_110330.dwg			

Ingenieurgesellschaft
von Lieberman
» Bauen und Umwelt «

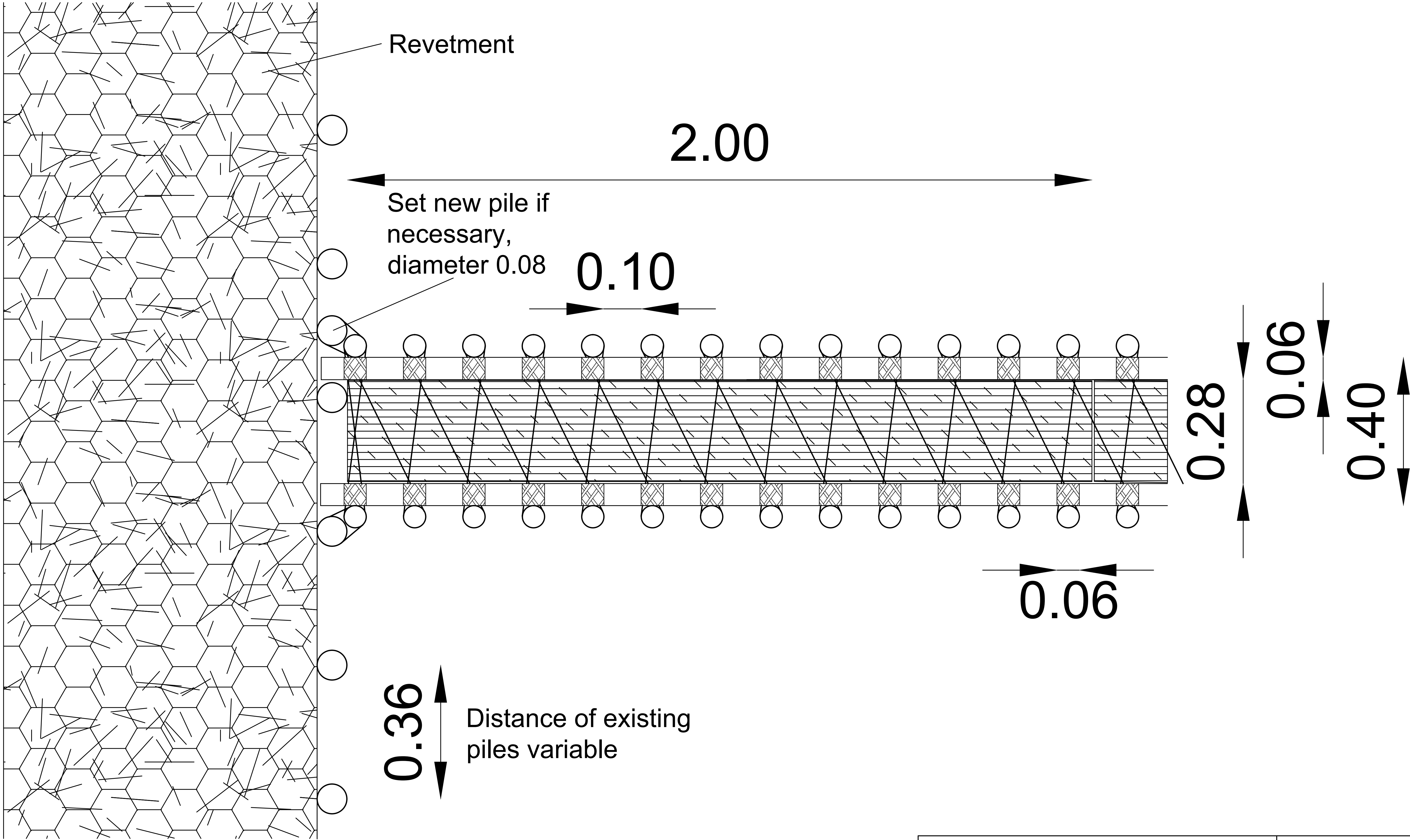
von Lieberman GmbH
Ruhrstr. 57, 22761 Hamburg
Tel.: 040 / 500 99 3 -0
Fax.: 040 / 500 99 3 -33



	Name	Date	Client:
Drawn:	T. Albers	23.08.2011	GIZ Soc Trang
Checked:			Content:
Project no.: 13713-01	Scale: 1:12.5	Attachment: 10	Bamboo longshore / cross-shore fence Connection Section I
File: bambus_110330.dwg			

Ingenieurgesellschaft
von Lieberman
» Bauen und Umwelt «

von Lieberman GmbH
Ruhrstr. 57, 22761 Hamburg
Tel.: 040 / 500 99 3 -0
Fax.: 040 / 500 99 3 -33

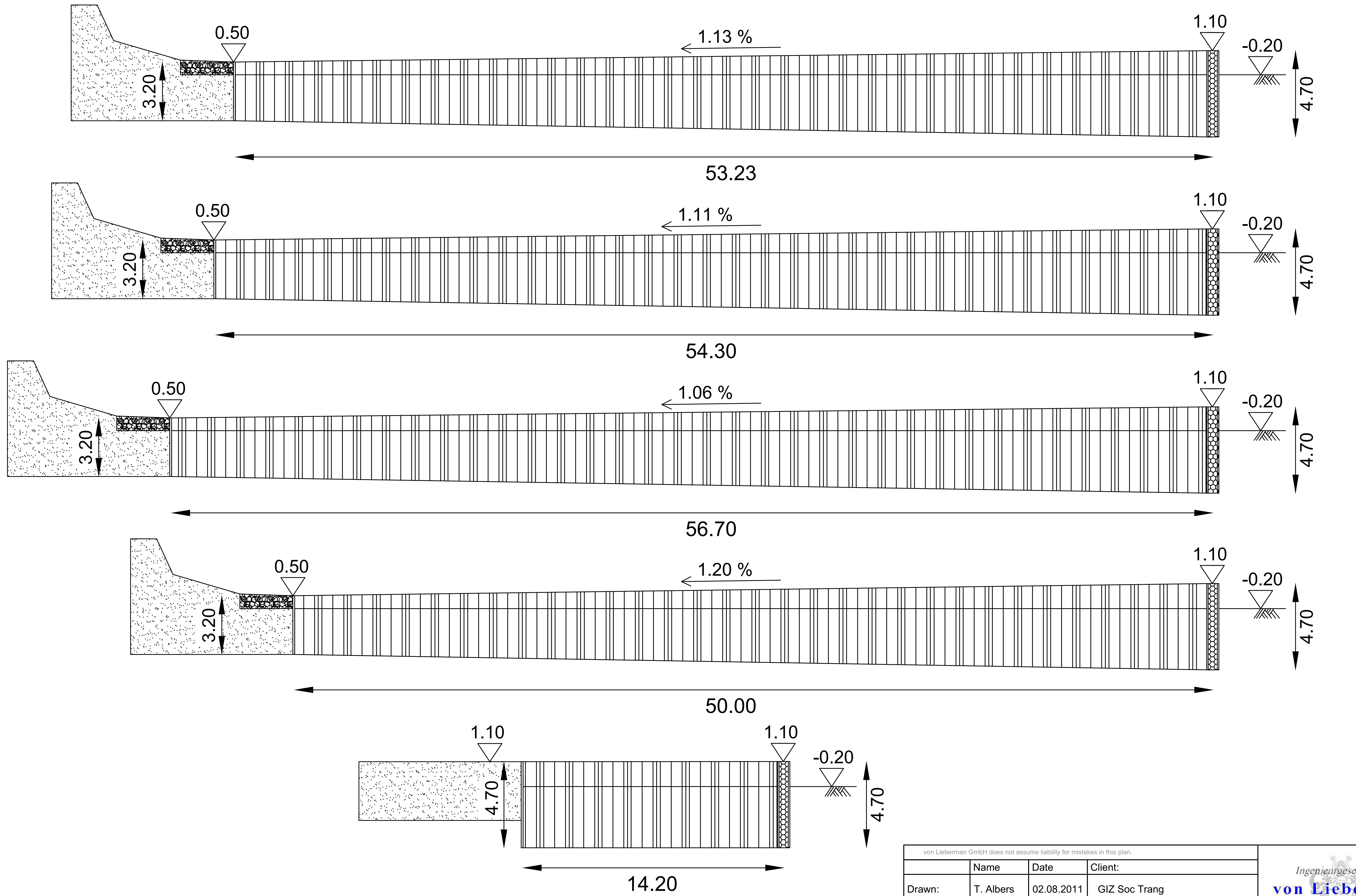


von Lieberman GmbH does not assume liability for mistakes in this plan.

	Name	Date	Client:
Drawn:	T. Albers	23.08.2011	GIZ Soc Trang
Checked:			Content:
Project no.: 13713-01	Scale: 1:10	Attachment: 11	Bamboo cross-shore fence Connection to revetment Section J
File: bambus_110330.dwg			

Ingenieurgesellschaft **von Lieberman** » Bauen und Umwelt «

von Lieberman GmbH
Ruhrstr. 57, 22761 Hamburg
Tel.: 040 / 500 99 3 -0
Fax.: 040 / 500 99 3 -33

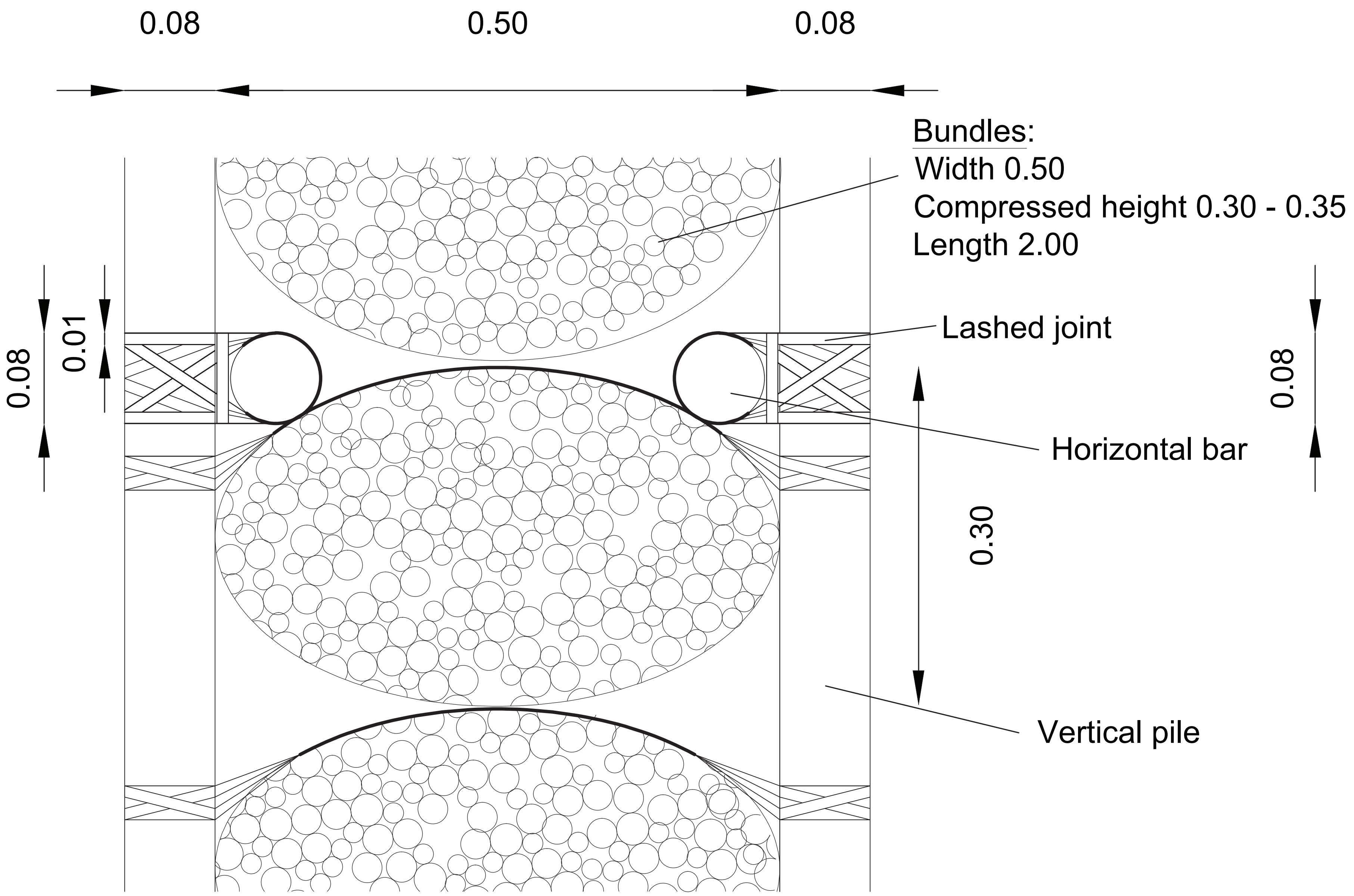


	Name	Date	Client:
Drawn:	T. Albers	02.08.2011	GIZ Soc Trang
Checked:			Content:
Project no.: 13713-01	Scale: 1:200	Attachment: 12	Bamboo fences Side view Section K-K
File: bambus_110330.dwg			

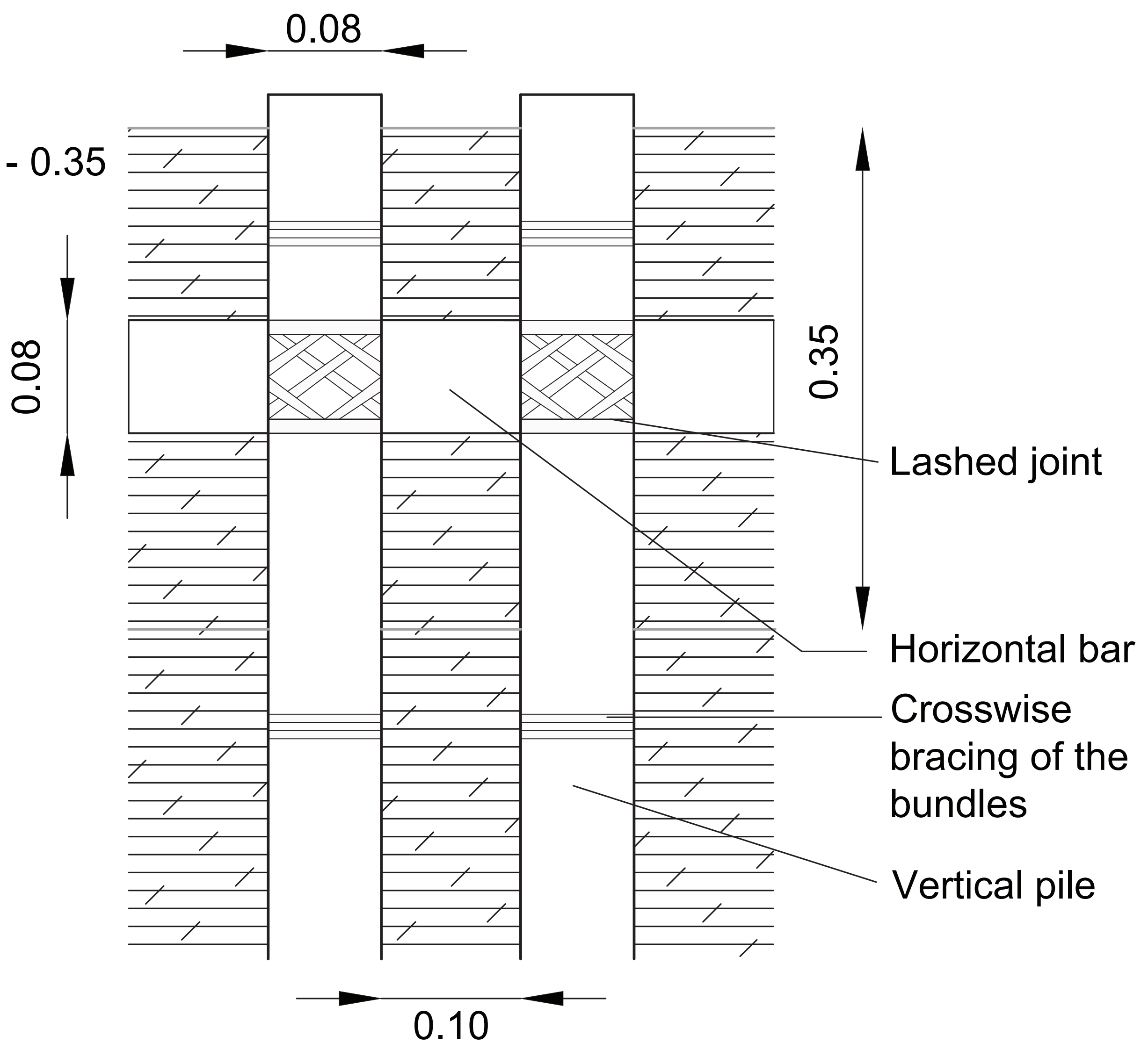
Ingenieurgesellschaft
von Lieberman
» Bauen und Umwelt «

von Lieberman GmbH
Ruhrstr. 57, 22761 Hamburg
Tel.: 040 / 500 99 3 -0
Fax.: 040 / 500 99 3 -33

Detail 1



Detail 2

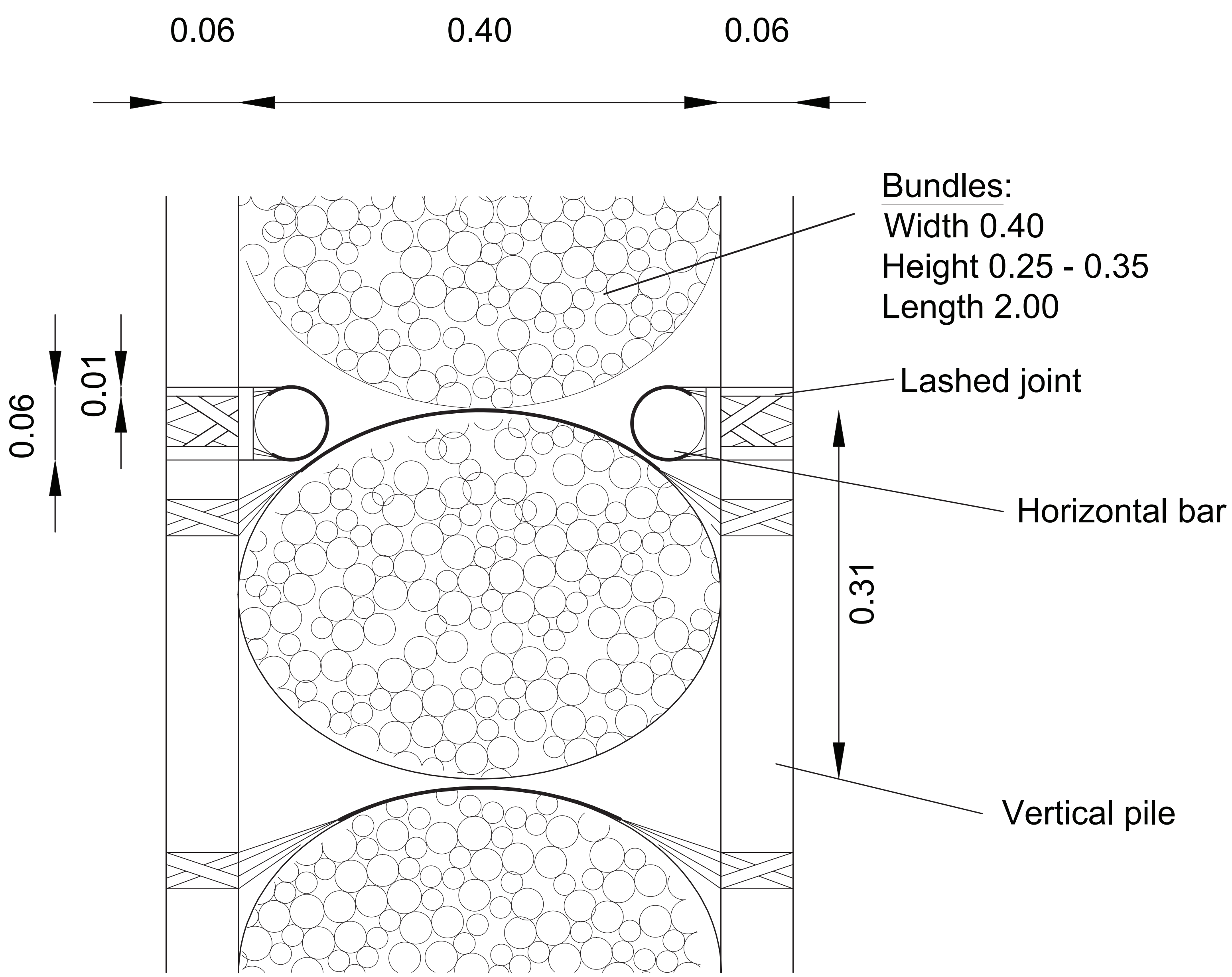


	Name	Date	Client:
Drawn:	T. Albers	15.10.2011	GIZ Soc Trang
Checked:			Content:
Project no.: 13713-01	Scale: 1:5	Attachment: 13	Bamboo breakwater / longshore fence Details 1 and 2
File: bambus_110330.dwg			

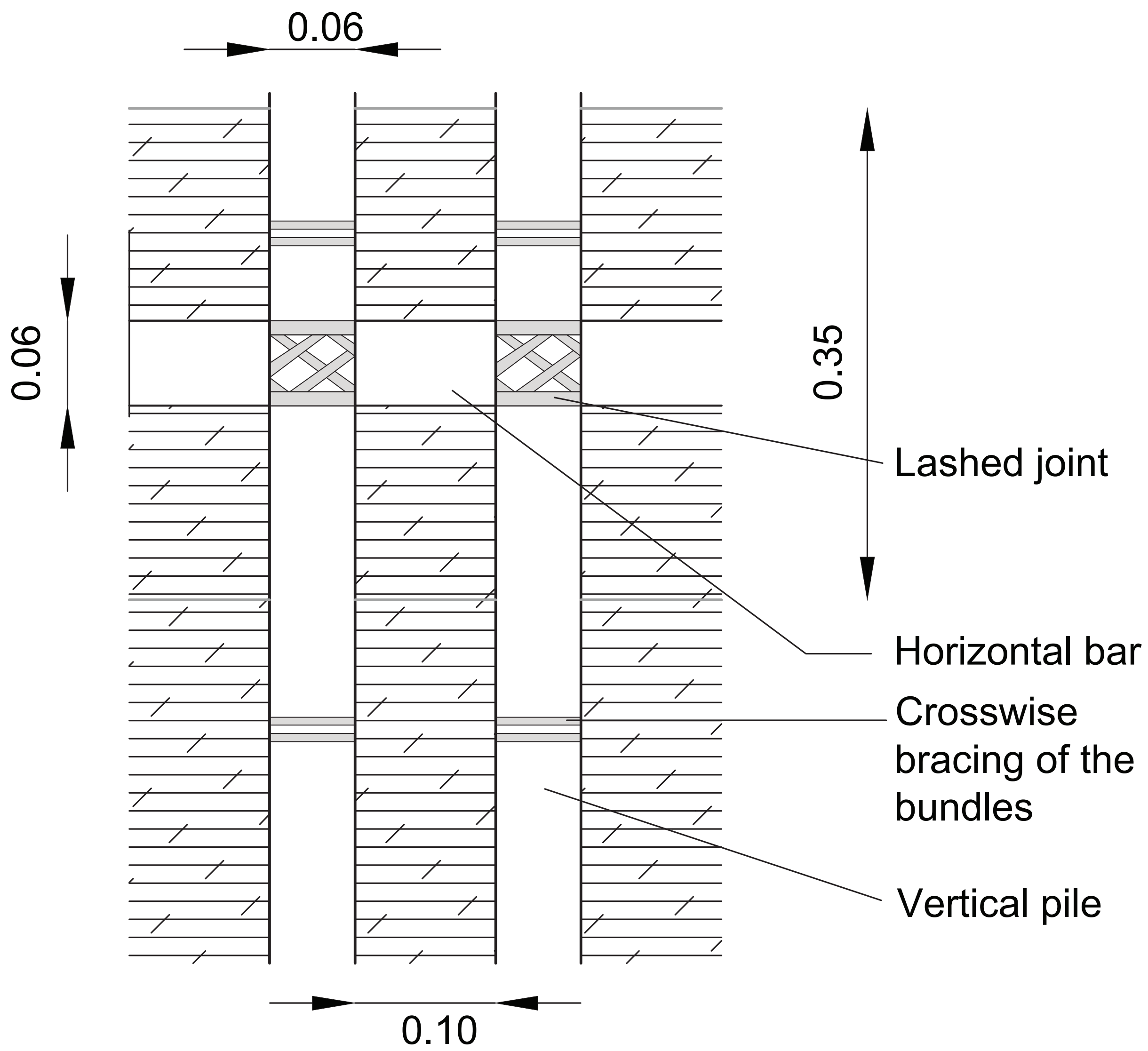
Ingenieurgesellschaft
von Lieberman
» Bauen und Umwelt «

von Lieberman GmbH
Ruhrstr. 57, 22761 Hamburg
Tel.: 040 / 500 99 3 -0
Fax.: 040 / 500 99 3 -33

Detail 3



Detail 4



	Name	Date	Client:
Drawn:	T. Albers	15.10.2011	GIZ Soc Trang
Checked:			Content:
Project no.: 13713-01	Scale: 1:5	Attachment: 14	Bamboo fence cross-shore Details 3 and 4
File: bambus_110330.dwg			

Ingenieurgesellschaft
von Lieberman
» Bauen und Umwelt «

von Lieberman GmbH
Ruhrstr. 57, 22761 Hamburg
Tel.: 040 / 500 99 3 -0
Fax.: 040 / 500 99 3 -33