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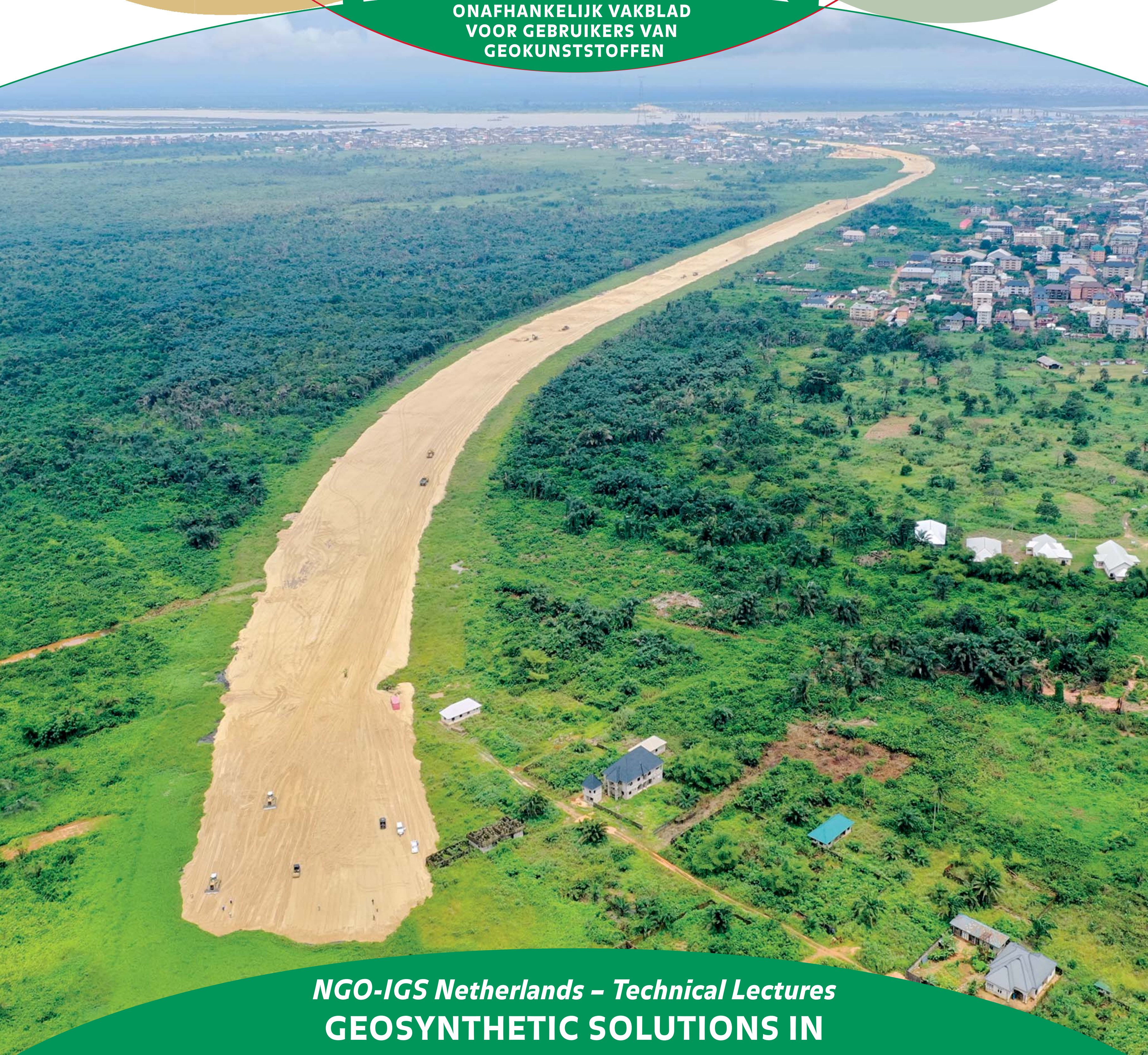

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GEOSYNTHETIC SOLUTIONS IN INTERNATIONAL PROJECTS

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BESTE GEOKUNST LEZERS,

Voor jullie ligt de zomereditie van Geokunst 2022. Het is mondiaal een turbulente tijd. Welvaart, vrede, internationale samenwerking en handel was voor iedereen een vanzelfsprekendheid. Sinds eind februari ziet onze wereld er echter ineens heel anders uit. Oorlog op het Europese continent… we zien verschrikkelijke beelden op TV. Steden in puin geschoten. Miljoenen mensen op de vlucht. Alle gebeurtenissen hebben ook impact op ons dagelijkse leven. De energie- en brandstofprijzen stijgen tot recordhoogten, prijzen van bouwmaterialen lopen extreem op. Dit alles geeft grote onzekerheden in de uitvoering van civiele bouwprojecten. Nagenoeg geen enkele partij geeft prijszekerheid over een lange termijn. Uit dit alles blijkt hoe intens de internationale markt met elkaar verbonden is. De oorlog in Oekraïne raakt ons allemaal.

We hopen dat er snel een vreedzame oplossing wordt gevonden, zodat er gewerkt kan worden aan herstel met een toekomstbestendig en vredig Europa. Respect, dialoog en internationale samenwerking zijn onmisbaar.

Vanuit de NGO-IGS Netherlands vinden we verbinding en internationale samenwerking heel belangrijk. Als organisatie streven we naar het bevorderen van kennis ten aanzien van het ontwerp en de uitvoering van constructies met hoogwaardige geomaterialen. Wij willen in het vakgebied de verbindende factor zijn tussen professionals. In dit kader organiseerde de NGO-IGS Netherlands op 8 maart 2022 een internationaal webinar. Het was de eerste keer sinds de oprichting van de NGO in 1983, dat een open on- line sessie is gehouden voor een groot internationaal publiek. De sessie werd bijgewoond door meer dan 100 (!) professionals uit de hele wereld, waaronder deelnemers uit Nederland, Duitsland, Frankrijk, UK, VS, Egypte, Brazilië, Polen, Griekenland, Italië, Canada en andere.

We kijken terug op een zeer inspirerende sessie met verschillende lezingen over oplossingen met geomaterialen bij verschillende internationale (water)bouwprojecten. In deze editie van Geokunst vinden jullie artikelen bij de gehouden presentaties. Gezien de internationale focus zijn de artikelen dit keer in het Engels. Het eerste artikel is geschreven door Max Nods (GeSySo) en Jeroen Dijkstra (Cofra). Het artikel gaat over een zeer groot project in Afrika, namelijk de bouw van de infrastructuur rond het 2e Niger Bridge project in Nigeria. Werner Bilfinger (Vecttor) volgt met een artikel over het ontwerp en de uitvoering van twee niet-conventionele paal-matras-constructies in Brazilië. Het derde artikel is van Janne-Kristin Pries (Naue) over kustbescherming met geotextiele zandcontainers bij Lubmin in Duitsland. Naast de artikelen zijn de slides van de presentaties beschikbaar op www.ngo.nl/agenda.

We willen de auteurs danken voor hun bijdrage aan de online sessie en de artikelen. Het succes van het internationale webinar smaakt naar meer! Er komt zeker een vervolg op dit mooie NGO-IGS evenement.

Ik wens jullie veel leesplezier.
Stay connected. Stay safe.

Rijk Gerritsen
Eindredacteur GeoKunst

COLOFON

Geokunst wordt uitgegeven door de Nederlandse Geotextielorganisatie. Het is bedoeld voor beleidsmakers, opdrachtgevers, ontwerpers, aannemers en uitvoerders van werken in de grond-, weg- en waterbouw en de milieutechniek. Geokunst verschijnt vier maal per jaar en wordt op aanvraag toegezonden.

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GEOSYNTHETIC SOLUTIONS IN INTERNATIONAL PROJECTS

Introduction

On March 8, 2022, the NGO – IGS Netherlands organized a technical webinar. It was the first time in the history of the NGO, that a session was held for an international audience.

We look back at an inspiring session with lectures on Geosynthetic solutions for several international projects. The session shows how the NGO facilitates professional connections between engineering firms, knowledge institutes, educational institutions, inspection institutes, contractors, authorities (municipal, provincial, national, water boards), producers and suppliers. The online session was attended by more than 100 professionals from all around the world, including attendees from The Netherlands, Germany, France, UK, US, Egypt, Brazil, Poland, Greece, Italy, Canada and many other countries.

The NGO stimulates the exchange of knowledge and proper applications of geomaterials. Geomaterials can be used in many construction projects in civil, hydraulic and environmental engineering. Better design and efficient building is in many cases possible by using properly selected geomaterials. In comparison with traditional solutions, it can be addressed as a method for reduction of CO_2-emissions (lower environmental impact), more sustainable building techniques and optimization of construction costs.

The possibilities of geomaterials in several international projects were nicely shown in the technical lectures during the webinar. The webinar started with Max Nods (GeSySo) and Jeroen Dijkstra (Cofra) on the 2nd Niger Bridge project in Nigeria. Werner Bilfinger (Vecttor) continued with a presentation about the design and execution of two non-conventional piled embankments in Brazil. At last, Janne-Kristin Pries (Naue) gave a lecture about coastal protection with geotextile sand containers at Lubmin in Germany. The speakers summarize their presentations in this Geo-kunst edition. The presentation slides are available on *https://ngo.nl/*. NGO would like to thank all the presenters and people attending the session.


ir. Max Nods
GeSySo, Netherlands


ir. Jeroen Dijkstra
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2ND NIGER BRIDGE PROJECT IN NIGERIA

Introduction

Nigeria is one of the most populated countries in Africa. With approximately 200 million inhabitants in a country three times the size of Germany and a massive growth rate, there is a large demand for infrastructure. This is also the case in Onitsha, a town in the centre of Nigeria. The city is located next to the river Niger. There is only one single two-lane bridge to cross the river. The bridge was constructed in 1964 and part of the Pan-African highway system. It provides the access to the massive city of Lagos, with over 15 million inhabitants in the south-western part of the country.

At the time of construction of the bridge, Onitsha had only 130.000 inhabitants. Currently the city has over 1.500.000 people. This enormous growth has resulted in increased traffic intensity, massive congestions, and an overuse of the not well-maintained bridge. A decade after the construction of the bridge it was already concluded that the capacity was insufficient, but it took over 40 years to start the actual construction of a new 1,590 m long second Niger bridge and corresponding infrastructure of 10 km length. In 2018 the locally well-known contractor Julius Berger Nigeria acquired the key project as a design and construct contract.

Design

The design of the infrastructure around to the bridge was done by Kempfert + Partner Geotechnik (K+G) based in Germany. They faced a considerable geotechnical challenge as the road connecting to the bridge had been planned in the swampy soft soil area just south of Onitsha. This location was not chosen on its geotechnical conditions but purely to prevent large demolitions of houses and to divert the traffic around the town. The soil conditions were very soft with very low undrained shear strengths (0-15 kPa) in the top meters. Below the very soft organic clay layer of variable thickness, the clay gradually improved in consistency and strength before changing into a consistent sand layer. The depth of the clay-sand boundary was found to be highly variable. At the start of the project, due to the difficult access to the area, only a few site investigation points were available. It was therefore a big challenge to provide a solid design in the preparation stage. The solution was found in the use of a number of geosynthetic solutions.

Solutions

The main ground improvement solution was the use of Prefabricated Vertical Drains (PVDs) combined with a basal reinforcement with high tensile strengths up to 2500 kN/m (type Stabilenka®). The PVDs allow accelerated consolidation of the weak layers and generate a more stable subsoil.
On the sections where PVD's were not able to fulfil the design requirements, Geotextile Encased Sand Columns (GECs, type Ringtrac®) were designed. The choice for these GECs was initiated by the very low strength of the clay and the local availability of sand. The confinement of the sand column by a confining geotextile was required to prevent the columns to bulge and limit the risk of construction failure. The design and bearing behaviour of the GECs is more complex than those for PVDs. In a PVD design, the soil compresses under a uniform load and well-known theory is used to calculate the duration and settlement that will occur. The complicating factor in a GEC design is the fact that the bearing elements (GECs) are significantly stiffer than the surrounding soil, therefore attracting a higher load concentration from the overlying embankment so that the GECs deform within the encapsulation of the geotextile. Conversely, the pressure acting on the adjacent soil is lowered, resulting in an overall reduction of the total settlements.

This specific behaviour of the GECs under loading is modelled by Raithel and Kempfert (2000), using a unit cell approach of hexagonal areas, which are derived from the triangular installation grid. The settlement design of a GEC is an iterative process in which the stresses on the column and the surrounding soil are distributed in such a way, that the deformation of the column equals the settlement of the surrounding soil. The deformation of the column includes the tensioning and horizontal radial deformation of the geotextile encasement, together with the vertical deformation of the sand. This leads to an uneven distribution of the vertical and horizontal stresses. With the low confining horizontal stress of the soil

Figure 1 – Project overview infrastructural works to the 2nd Niger Bridge project in Nigeria

Figure 2 – Installation of high strength basal reinforcement.

Figure 3 – Installation of Geotextile Encased Sand Columns (GEC) as soil improvement technique for the very soft soil conditions to create bearing capacity.

and much higher horizontal stresses in the column, the column wants to bulge. This is prevented by the tensioning and straining of the geotextile encasement, until an equilibrium has been reached. In fact, this strain-dependence of the equilibrium is very specific for the system, the settlements that will occur and the corresponding design procedure.
The global stability of the embankment was improved for both solutions (PVD and GEC) by adding additional strength from the horizontal inclusion of high strength basal reinforcement.

Installation

In 2019, Cofra acquired the contract for the execution (construct only) of the ground improvement comprising of 1,400,000 m PVD and 16,000 GECs. For the PVD installation one single installation mast was mobilized to site, whilst using a local excavator to optimize the mobilization and limit transports. The PVDs were installed within a few months' time from a working platform of sand in a triangular grid pattern with spacings between 0.8 and 1.5 m, without specific issues. After the PVD installation, the GEC installation was started, using three installation units. Underneath the future slopes of the embankment a triangular grid of 2.30 m was used with a GEC diameter of 800 mm to reach a replacement ratio of 10%. Under the main embankment and traffic area, a grid of 2.07 meter had to be installed to reach a replacement ratio 15% with the same column diameter of 800 mm. Huesker supplied the GEC geotextiles and high strength geotextiles.

Because of the weight of the machines in relation to the very soft soil conditions, the installation was performed from wooden mats, founded on the already installed columns, to ensure installation stability conditions. The additional benefit of this working method is that the columns are being prestressed by the weight of the installation equipment. This increases the functionality of the geotextile encased column system.

Figure 4 – Installation of Prefabricated Vertical Drains (PVD) to accelerate consolidation of the soft layers and limit residual settlements.

Challenges

The GEC installation faced a few challenges to overcome. The stiffer clay at the bottom, combined with the highly variable depth of the sand layer, challenges the quality control of the columns. A fixed installation depth was not possible with height differences of decimetres between adjacent piles. This made a solid steering mechanism on installation parameters very important. A set of handover criteria was determined in cooperation with the designer and main contractor based on frequency, installation speed and pull-down force. The working platform was compacted to a high density by all the traffic movements along the sections, leading to production delays during installation. Besides these technical challenges and how to deal with them, the corona pandemic turned out to be the biggest challenge.

Outlook

The installation of the columns has nearly been finished at the time of writing this paper. Ground improvement has provided a solid base for the superstructure. Bridge construction nears completion. The official opening of the road including the bridge is scheduled for 2023, providing a sound infrastructure base for economic and social traffic in the decades to come to Nigeria.

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dr. Werner Bilfinger .
Vecttor, Brazil

TWO NON-CONVENTIONAL PILED EMBANKMENTS IN BRAZIL

Introduction

Piled embankments are an interesting solution for soft soil environments, where the construction of conventional embankments is often associated with stability problems and/or excessive settlements. Instead of loading surficial soft soil, the embankment weight is carried by piles and founded on deeper seated, more competent soil layers. To improve the load transfer from the embankment to the piles, usually pile caps are used.

Principles

The main principle associated with piled embankments is soil arching. This important principle allows the use of discrete pile caps instead of a continuous slab. The principle is described in an illustrative way by Terzaghi in 1943 with the "trap door".

The Swedish Road Board (1974) is one of the first publications that presents an empirical design methodology. Hewlett and Randolph (1988) presented a landmark paper, with a sound theoretical approach, as well as experimental studies of the soil arching effects associated with piled embankments. Several other studies and publications are available about piled embankments.

The use of geosynthetics at the base of the embankments improved the performance of piled embankments, allowing the use of wider pile and pile cap spacing. Important publications that include the design of piled embankments with the use of geosynthetics are the British Standard BS 8006 (2010) and EBGEO (2011).

The landmark publication of Van Eekelen (2015) presents a new analytical design model, validated numerically and experimentally, for piled embankments with basal reinforcements. Van Eekelen's work was later adopted in the Dutch Design Guideline CUR 226 (2016).

In addition to arching between pile caps, for the successful use of piled embankments, horizontal forces are necessary to equilibrate internal earth pressures. Without geosynthetics, this equilibrium is usually achieved using raking piles. When using basal reinforcements in a symmetric geometry, horizontal self-equilibrating forces guarantee equilibrium. However, for non-symmetric geometries, like existing embankment enlargements, other measures are necessary to guarantee equilibrium.

Case Histories

The two presented cases are typical 'non-greenfield' projects, i.e., the piled embankments were built close to existing embankments, in a non-symmetrical geometry.
Design procedures were based on the methodology proposed in BS 8006, adapted by De Mello & Bilfinger (2004), adding effective cohesion to the soil shear strength. When embankments are built with lateritic soils, that present effective cohesion, a more economic design is possible when cohesion is included in the determination of the soil shear strength.

Case History 1

The project consisted of a highway enlargement with variable height. Local subsoil relevant for the project is very soft organic clay, so the construction of a conventional embankment was not possible due to potential stability and settlement problems. Figure 1 presents a simplified cross section, including the existing embankment and the embankment to be built.

For the design, the following key aspects had to be considered:
- an embankment with variable height;
- soft soil with variable thickness and shear strength;
- need to maintain part of the road operating;
- strict settlement criteria during the design life.

Figure 2 presents the design solution, that includes the following non-conventional features.
- A slightly sloping embankment base, to reduce the height of the cut on the left side of the figure, to avoid stability problems of the existing embankment, minimize interference with the operating road, and avoid excessive loads on the piled embankment.
- Anchoring of the geogrid in an area not founded on piles, to guarantee horizontal equilibrium.

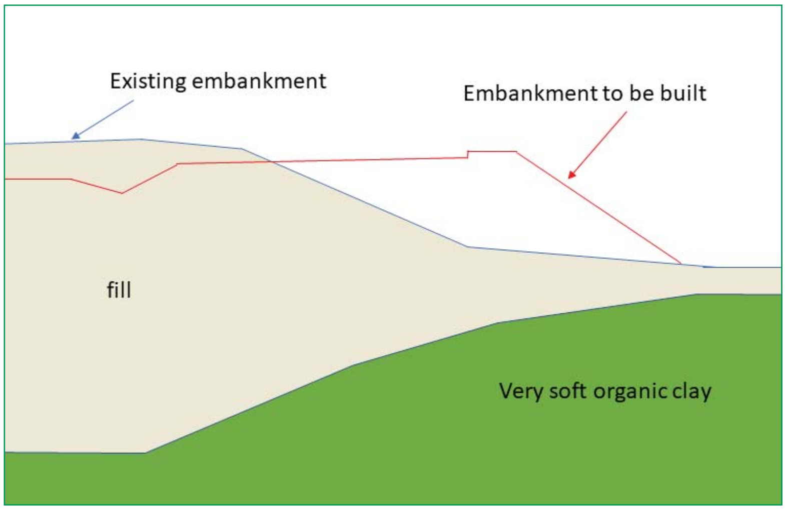

Figure 1 – Simplified cross-section of the existing embankment and the extensions to be built on very soft organic clay.

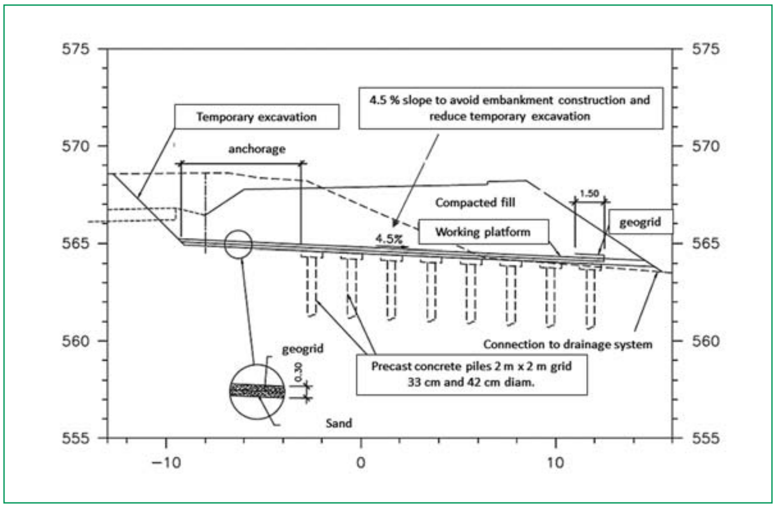

Figure 2 – Cross-section with the designed piled embankment, including a slope of 4,5% to limit groundworks as much as possible.

Due to the relatively stiff geogrids, the horizontal displacements were kept compatible with the pile behavior.
– Temporary partial removal of the existing embankment and extension of the piled embankment in this area, to reduce future settlements, especially in the region of the interface between the embankment with and without piled foundation.

Case History 2

The project consisted of a piled embankment built inside a container terminal. The major challenge of the project was the typical soil profile that includes more than 35 m of marine sediments, mainly soft to very soft clay.
During construction, excessive horizontal displacements (approximately 40 cm) of the sheet pile wall of the quay structure occurred. The problems were associated with the constructive sequence and unforeseen deeper seated very soft soil and led to the decision to temporarily avoid applying loads on the surface close to the quay structure. The chosen solution was the construction of a piled embankment, replacing part of the soft soil treatment (Prefabricated Vertical Drains + surcharge). Figure 3 presents a typical cross section of the piled embankment. Figure 4 presents a detailed view of the piled embankment and the interface with the quay structure.

The design of the piled embankment included the following non typical characteristics:
– Relatively small embankment height (1.50 m).
– Highly variable surcharge, around 50 kPa, associated with the use as container terminal. Additionally, the position of the loaded areas varies frequently.
– Difficult anchoring conditions, especially at the interface to the quay structure.
– Some utilities, including culverts, had to be built inside the embankment.
– A residual settlement of the surrounding soil of 40 cm in 20 years was foreseen. For that reason, the piles of the piled embankment were designed as "floating piles", different from the piles of the quay structure, which were founded almost 20 m deeper, in residual soil.

To avoid tilting of the pile caps due to the possible non-symmetrical surcharges – equipment and containers at variable positions – the pile caps were structurally fixed to the specially reinforced concrete piles.

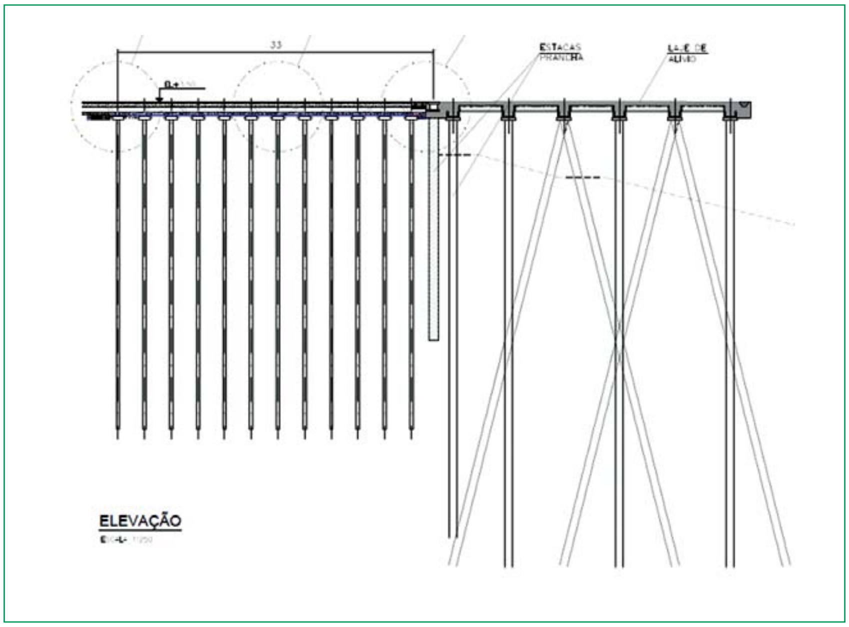

Figure 3 – Cross-section of the designed piled embankment for a container terminal with 35 m of marine sediments.

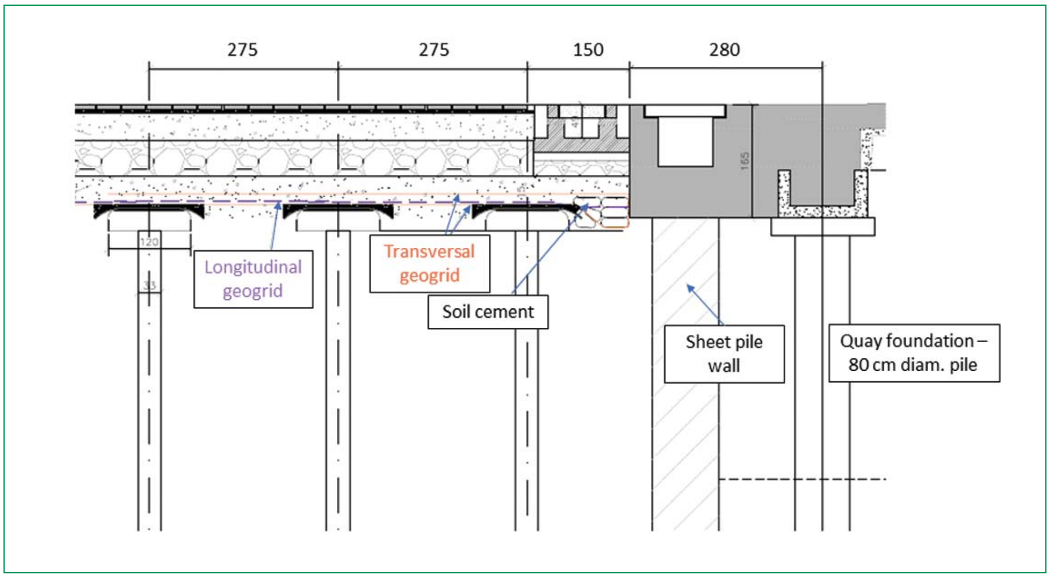

Figure 4 – Detail of the cross-section of the piled-embankment and the interface with the quay structure.

Concluding remarks

Piled embankments are proven geotechnical solutions and have been applied successfully for several decades. Design and construction methods evolved, which has led to more reliable and economic solutions.
For design and construction, in addition to soil arching between pile caps, with or without basal reinforcements, other verifications and design details may also be important. For example, non-symmetrical loads may generate non-foreseen pile cap movements, especially for low height embankments. Another important topic is the overall stability: in the case of non-symmetrical embankments, horizontal equilibrium may not be automatically guaranteed by symmetrically installed basal reinforcements.

Available design methodologies certainly do not explicitly include verifications for all possible conditions and, therefore, careful engineering judgement to evaluate possible non foreseen scenarios should always be part of design.

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COASTAL PROTECTION WITH GEOTEXTILE SAND CONTAINERS AT LUBMIN IN GERMANY

Introduction

In the area of Lubmin on the Baltic Sea, the existing coastline with sand dunes has been severely impacted by multiple storm surges. A solution is being implemented with an underground protection structure using Geotextile Sand Containers (GSC). To reinforce approximately 2 km of coastline, a total of 34,000 elements are being installed of approximately 1.4 tonnes each.

Geotextile Sand Containers (GSC) are soft and flexible construction elements which can adapt very well to the surrounding coastal conditions and can provide effective erosion control. Geotextile Sand Containers are a worldwide used construction method for anti-scouring for example around bridge foundations, offshore wind parks or beach protection. They can be applied in sand dune beach protection systems, like the project in Lubmin. In Nigeria at the Second Niger Bridge project, Geotextile Sand Containers were used in a different application, being a scour protection system around the bridge foundations in the middle of the river.

Normal sand subsoils can be quite vulnerable to erosion, when subjected to large hydraulic forces from wave attacks, flows and currents. By putting sand into high performance nonwoven elements (containers), stable confinements can be realized as a durable and permanent solution. In order to be able to guarantee the durability of the structures, comprehensive knowledge of the design, dimensioning and the project boundary conditions is required.

Figure 1 – Construction process of a structure with Geotextile Sand Containers, filled with local beach sand – and installed as an underground coastal protection measure in the dune core of the sandy beach behind.

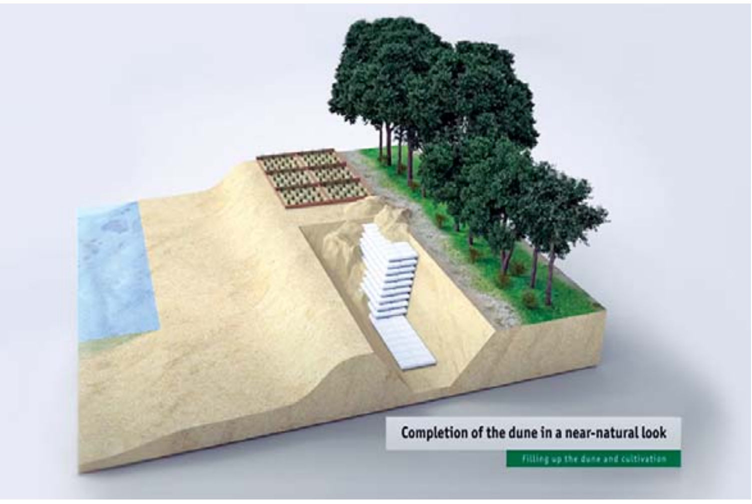

Figure 2 – Solution impression with 3D-model on coastal protection system with geotextile sand containers in Lubmin.

Coastal protection requirements

The task of coastal protection is to ensure safe and complete protection against storm surges and to safeguard values in the protected area. The development of a technically adequate, sustainable, and economically justifiable flood protection is required that takes into account both ecological and human concerns. Building with sand-filled geotextile elements can meet the coastal protection requirements in most cases. The characteristics of nonwoven Geotextile Sand Containers are:

- Flexible, adaptable elements which can absorb (hydraulic) impacts and have deformation capacity.
- Filling with local sand limits transport of building material as much as possible.
- Reducing CO_2-emission and environmental impact, compared to traditional solutions with rock, concrete or asphalt.
- Available in nonwoven geotextile polypropylene (PP), but also in fully biobased and biodegradable nonwoven material.
- Containers with 1.0 – 2.5 m^3/element are more redundant in case of failure compared with geotextile tubes with much longer lengths of 25-100 m.
- Robust geotextile with puncture resistance depending on the mass/m^2.
- Easy filling, closing technology and installation process.
- Cost-efficient compared with alternative solutions.

Design and dimensioning

The design of coastal dune protection systems with geotextile sand filled containers must be carried out on several levels. It can be divided into three main design parts for dimensioning and interactions:

- Overall structure geometry (internal, structural,

and geotechnical stability).
– Geotextile sand container dimensions.
– Material characteristics.

For state-of-the-art design and construction methods, the following attention points need to be addressed:
– Ensure short- and long-term stability under static loads (dead load, ballast, groundwater, design flood, etc.).
– Ensure stability under dynamic load (wave run-up, wave overflow, etc.).
– Ensure erosion stable encapsulation of the fill material in the geotextile sand container (define soil retention, check filter effectiveness of the geotextile).
– Ensure sufficient resistance to impact loads from flotsam (drifting wood or other floating debris)
– Ensure sufficient resistance to abrasion.
– Meet hydraulic requirements and allow the flow of precipitation water through the structure without damage.
– Consider chemical and biological influences and UV radiation.

Design approach and research

Extensive studies and research on the stability of geotextile sand container constructions were carried out at the Leichtweiss-Institute for Hydraulic Engineering and Water Resources, Braunschweig, Germany, under the leadership of Professor Hocine Oumeraci. Since 2002, there has been a significant increase in knowledge regarding the dimensioning of the hydraulic stability of geotextile nonwoven containers. These studies result in design approaches with proven practice. A parameter-orientated design approach and a process-orientated design approach have been developed. These design approaches concentrate on the hydraulically based failure cases when considering geotextile sand containers, which are divided into sliding, tilting and internal sand movement and deformation.
The dimensioning of the nonwoven containers, in particular their lengths and weights, is the decisive criterion for stability. The following design approaches are derived from this.

The state-of-the-art parameter-oriented description of the stability behaviour of geotextile sand containers is based on the so-called Hudson formula (1959), which was further developed especially for this purpose, and which enables the design of impermeable, freely flowable cover layer elements. Oumeraci et al 2002 established a dependence on the crusher code ξ_0 for slope elements and the relative freeboard R_c/H_s as determining factor for the crest elements.
The process-oriented design approach assumes a balance of forces between the mobilized forces due to friction between the containers and the weight of the containers. The stability formula for gliding and tilting results in the required sand container length l_c and the required weight G_c of the sand containers. It is empirically adapted with force coefficients and deformation coefficients, which are determined experimentally.
Accordingly, the geotextile sand container is stable against sliding or displacement if the resisting forces are greater than or at least equal to the mobilizing forces. The lifting force counteracts the weight force and thus partially cancels it out.

Figure 3 – Construction process of a structure with Geotextile Sand Containers as underground coastal protection measure in the dune core of the sandy beach behind.

Figure 4 – Exact and stable positioning of the Geotextile Sand Containers of approximately 1.4 ton/element using crane clamping.

Coastal protection Lubmin

In the area of Lubmin on the Baltic Sea in Germany, the existing coastline with sand dunes, as the sole coastal protection, has been severely impacted by multiple storm surges. To improve the storm protection measure, two kilometres of dune along the coast of Lubmin have been reinforced with sand containers.

The limited space available on site (protected area off the coast and the village of Lubmin directly behind the dune) meant that the coastal protection dune could not be constructed in accordance with its intended cross-section. In the event of the dune being threatened with complete erosion in the event of a storm surge, an additional underground defence construction is realized protecting the hinterland. This reinforcement of the dune was formed in Lubmin with 34,000 sand containers of Secutex® Soft Rock delivered by Naue. The elements weigh approximately 1.4 tonnes each and are used to construct the underground coastal defence structure. Each geotextile sand container provides sufficient stability for the given project specific conditions, verified with extensive design calculations.

The sandbags are installed in the area at the end of the sand beach that must remain standing during a storm tide. For this purpose, the sand is first removed in the safety part of the dune to construct a deep and stable foundation base. The bags are laid in two rows, inclined to the long side and stacked in an offset manner (see figure 3 and 4).

Concluding remarks

The geotextile sand container structures as reinforcement for dunes are covered with sand for most of their useful life. Being covered with sand, the structure is no disturbing factor in the landscape. Also, there are no restrictions to use the beach for tourism. Only after super storm events and severe erosion, the sand in front of the structure could wash away. With such storm surge the underground structure could become visible. In such case maintenance and repair works are to be planned for example with beach nourishment covering the structure again and making the surrounding appearing as a natural beach again.

The project owner and residents in Lubmin are satisfied with the coastal protection solution and are pleased with the improved safety and the elegance of non-visible coastal defence structure. Since the construction the structure withstood already several high tides and storm conditions. Comparable coastal protection structures have already been realised in Germany in Rerik and Warnemünde.
Currently, geotextile sand container structures are popular on the Mecklenburg-Western Pomerania Baltic Sea coast and are the preferred option for wall type protective structures in sand dunes. Reasons for this are the easy installation, flexibility, initial costs, durability (low follow-up costs in case of local damages) and the high resistance to dynamic loads.

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