THE RUSH TO MAKE NEW LAND IN VIETNAM
balancing the needs of agriculture and industry

SAVE TIME, MONEY & THE ENVIRONMENT
replacing rockfill berms with sandfill tubes

WHEN DISPOSAL SITES ARE HARD TO FIND
prepare and reuse soft dredged sediments
Guidelines for Authors

*Terra et Aqua* is a quarterly publication of the International Association of Dredging Companies, emphasising “maritime solutions for a changing world”. It covers the fields of civil, hydraulic and mechanical engineering including the technical, economic and environmental aspects of dredging. Developments in the state of the art of the industry and other topics from the industry with actual news value will be highlighted.

- As *Terra et Aqua* is an English language journal, articles must be submitted in English.
- Contributions will be considered primarily from authors who represent the various disciplines of the dredging industry or professions, which are associated with dredging.
- Students and young professionals are encouraged to submit articles based on their research.
- Articles should be approximately 10-12 A4s. Photographs, graphics and illustrations are encouraged. Original photographs should be submitted, as these provide the best quality. Digital photographs should be of the highest resolution.
- Articles should be original and should not have appeared in other magazines or publications. An exception is made for the proceedings of conferences which have a limited reading public.
- In the case of articles that have previously appeared in conference proceedings, permission to reprint in *Terra et Aqua* will be requested.
- Authors are requested to provide in the “Introduction” an insight into the drivers (the Why) behind the dredging project.
- By submitting an article, authors grant IADC permission to publish said article in both the printed and digital version of *Terra et Aqua* without limitations and remunerations.
- All articles will be reviewed by the Editorial Advisory Committee (EAC). Publication of an article is subject to approval by the EAC and no article will be published without approval of the EAC.
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SEMINARS / CONFERENCES / EVENTS

2014 begins with the IADC Dredging Seminar in Brisbane, Australia, OAS-CIP conference in Argentina, PIANC in San Francisco and WEDA in Toronto, Canada
The dredging industry is not what it used to be. It is, in fact, much more. In the last decade, a transformation has occurred: The major international dredging companies have shifted from the role of subcontractor for various dredging operations such as maintenance dredging for ports, harbours and rivers to that of main contractor for the construction of new maritime infrastructure projects.

Part of this transformation is the result of decades of large investments in research and development. This R&D has resulted in incredible advances in dredging technologies – larger trailing suction hopper dredgers and cutting suction dredgers with more powerful engines and pumps and longer and stronger drag arms. Much purpose-built water- and land-based equipment has been added to the traditional dredging fleets. And the technical advantages of GPS, sonar and other environmental monitoring systems are constantly implemented in dredging projects.

In addition, the international dredging contractors have taken a pro-active approach to the emergence of environment as a key issue. R&D specifically dedicated to finding innovative techniques which enhance sustainability is common amongst the major contractors. This research strives to protect the environment from the consequences of climate change and rising sea levels. At the same time, it provides the means to increase economic opportunities for a prosperous society, as well as to build land to relieve the pressures of overpopulation.

Another significant asset is an increase in the number of well-educated young engineers attracted to the dredging profession. Dredging is a high-tech industry with room for career advancement; it is an industry that invests not only in research but also in its people.

The combination of these factors – innovation plus the expertise and entrepreneurial spirit of people in the dredging industry – have made it possible to open new maritime infrastructure markets for port development, land reclamation projects and offshore energy projects. The industry has risen to the occasion to fulfil the worldwide demand for deeper harbours and more offshore energy, both traditional and renewable. And it has combined this with environmental responsibility.

Amongst all these dredging activities, land reclamation remains a driving force. As can be seen in this issue of Terra et Aqua, contractors working in Southeast Asia and the Far East have provided some interesting advances in techniques for subsoil consolidation and dike construction. In Vietnam, South Korea and Japan, natural land is often limited or dedicated to much needed agricultural purposes. Consequently, growing populations and increasing industrialisation have created an impetus to invest in research for improved land reclamation techniques. In each of the articles in this Terra, new methods for providing land fill and maximising the creation of new land are presented, methods which at the same time guarantee food supplies, reduce the need for dredged materials disposal sites by recycling for beneficial uses and expedite the preparation of new land.

As the year 2013 draws to a close, it is not redundant to emphasise that the constant quest for new solutions to ongoing challenges – and the ingenuity to foresee where the next challenge may appear – continues to characterise the modern dredging industry. And reporting on these developments remains the mainstay of Terra et Aqua.
ABSTRACT

This article describes the subsoil improvement works realised in the Dinh Vu Industrial Zone, Haiphong, Vietnam. The Dinh Vu Industrial Zone is located along the Cam and Bach Dang Rivers adjacent to the sea. Before land reclamation, the area was below the water level of a pond. The land was reclaimed by using sand dredged from the sea and pumped into the area to be reclaimed (thickness of the sand 3 m). The subsoil in Dinh Vu consists of soft alluvial and marine clay deposits with a thickness of about 35 m. The soft subsoil has low bearing capacity and excessive settlement characteristics.

In order to accelerate the settlement process, subsoil consolidation has been performed in an area of 40 ha in the industrial zone, including installation of prefabricated vertical drains (PVDs) combined with a surcharge preloading. PVDs provide a shorter drainage path in a radial direction which decreases the excess pore pressure and increases the effective stress. In order to realise the design of PVDs (spacing and depth), a pre-soil investigation was performed and theoretical predictions of settlement were calculated.

During the project the consolidation process was recorded with settlement marker plates. Settlement recordings have been analysed using the Asaoka method. Theoretical consolidation behaviour predicted before subsoil improvement matched the recorded consolidation. A model was developed and in order to test its accuracy under different loads, a trial embankment was performed (thickness of sand 6 m). A post-soil investigation has also been realised and compared to the pre-soil investigation highlighting the subsoil improvement.

INTRODUCTION

Vietnam has been a predominantly agricultural civilisation based on wet rice cultivation. A few years ago, governing authorities introduced economic reforms to encourage the growth of industries and commerce which lead to an increase and diversity in economic activities. To serve that target, Vietnam has converted agricultural land into industrial land intensively since the economic reforms. However, the ratio of agricultural land must be secured while industrialisation is in progress. In fact, the conversion of agricultural land into industrial land has already exceeded the limit. Therefore land reclamation could be a good solution in order to create more economic activities without using land reserved for agricultural purposes.

LAND RECLAMATION PROJECT DESCRIPTION

In December 2011, Dinh Vu Industrial Zone (DVIZ) was chosen by Bridgestone to establish its new tire plant. The area to be reclaimed is 102 ha of which 40 ha was requested to be consolidated by DVIZ.

Settlement recordings have been analysed using the Asaoka method. Theoretical consolidation behaviour predicted before subsoil improvement matched the recorded consolidation. A model was developed and in order to test its accuracy under different loads, a trial embankment was performed (thickness of sand 6 m). A post-soil investigation has also been realised and compared to the pre-soil investigation highlighting the subsoil improvement.

Above: Waiting for natural settlement to consolidate subsoil is a long and thus costly process. The placement of Prefabricated Vertical Drains (PVDs) expedites the process, but must be prepared by soil investigations and carefully calculated for depth and spacing.
The settlement process. The consolidation process consisted of the installation of Prefabricated Vertical Drains (PVDs) up to a depth of 25 m combined with a surcharge preloading (area reclaimed up to +6.5 mCD) (Figure 5). The contractual specifications between the client and DVIZ required an achievement of a degree of consolidation of 90% (in the area to be handed over at a final level of +4.8 mCD) and 75% (in the area to be handed over at a final level of +5.8 mCD) of the primary consolidation. When consolidation criteria have been reached, the surcharge can be removed to the final level required for the hand-over (Figure 6).

Within the framework of the project, soil investigation has been performed before land reclamation in order to realise the design of PVDs (spacing and depth) and theoretical predictions of settlement have been calculated. During this project the consolidation process was recorded with settlement marker plates. Settlement recordings have been back analysed. Furthermore, a post-soil investigation has been performed after completion of the consolidation criteria to compare geotechnical parameters before and after subsoil consolidation.

GEOLGY AND SITE CONDITION

The land to be reclaimed is located on the right bank of the Cam River adjacent to the sea. This area is directly affected by the tidal regime. Geological phenomena in the region are mainly storage accumulations of materials originating from rivers and seas; concretely there are silt aggregations brought about by the flow of the Cam River and the tide. The subsoil in Dinh Vu consists of soft alluvial and marine clay deposits with a thickness of about 35 m. The two first layers are softer and have an average thickness of 13 m, underlain by medium stiff to stiff clay layers (Figure 7).

SOIL INVESTIGATION

In order to determine soil parameters needed to calculate the settlement, a soil investigation was carried out. Six deep boreholes have been drilled with Standard Penetration Tests (SPT) and the lab tests included particle size analysis, unit weight, Atterberg limits, direct shear test and consolidation test. Soil parameters used for settlement calculation are given by the soil investigation.
An average profile has been used for the model coming from data of the 6 boreholes (see Table I). The secondary compression index was not tested in the laboratory; therefore values have been adapted from literature resources. The horizontal coefficient of consolidation has not been defined, but a ratio of 2 is assumed for the clayey materials as it is often the case in natural sediments that the horizontal permeability is larger than the vertical permeability (a ratio of 1 is assumed for the mud).

For all layers a preconsolidation pressure of about 60kPa has been found from the lab testing results. Such a preconsolidation stress, however, seems to be too high. Because of this uncertainty and the important effect of this, the preconsolidation stress will (conservatively) be neglected in the calculations.

SUBSOIL IMPROVEMENT WORKS

The low bearing capacity and high compressibility of soft subsoil affects the long-term stability of buildings. Therefore, the stabilisation of soft subsoil before commencing construction was recommended.

Surcharge (preloading) is one of the most successful techniques for improving the shear strength of soft subsoil because it loads the ground surface to introduce a greater part of the ultimate settlement that is expected to bear after hand-over. When PVDs combined with surcharge preloading are applied, vertical drains provide a much shorter drainage path in a radial direction which decreases the excess pore pressure and increases the effective stress; this reduces the required preload period significantly (see Figure 8).

In order to determine the PVD design – depth of the PVDs and spacing between PVDs – settlement calculations have been performed based on the formula of Terzaghi assuming one dimensional deformation. Installation of the PVDs disturbs the soil surrounding the PVD which has an impact on the rate of consolidation. For this reason the smear effect was taken into account in the model. The ratio \( d/d_w \) was chosen as 2 (size of PVD and mandrel) and the ratio \( k_h/k_v \) of 3 is assumed. The target was to reach 90% of consolidation under a load which is a final level +4.8 mCD or 75% of consolidation under a load which is a final level +5.8 mCD. Calculation coming from the model indicated that without any PVD installation the time required to reach 90% of consolidation is more than 10 years. With PVDs, the time required to reach 90% of consolidation is reduced to 3 months. Thanks to settlement calculation, the design of PVD has been chosen as follows: Spacing between 2 PVDs is 1 m (square grid) and depth of the PVD is 25 m which means that PVD also penetrate layers 3 and 4.

Figure 3. Aerial view of the reclamation area.
MONITORING AND ANALYSIS

The consolidation process was recorded with settlement marker plates (Figure 9). Settlement and sand elevation data recorded on site are shown in Figure 10. As can be seen, the area has been filled up to +6.7 mCD. During the surcharge installation, the settlement velocity is significant; then the settlement velocity decreases, until the installation of PVDs. After PVD installation, the settlement velocity increases again.

Variations in the settlement velocity after PVD installation are mainly a result of the variations of the ground water level (hydraulic land filling in an area close to the settlement marker plate). Settlement develops mainly during the surcharge installation and during the two months after PVDs installation. Settlement recordings (from 39 rod settlement gauges) were analysed by the Asaoka method in order to obtain the final settlement. From these analyses final settlements vary between 0.7 m and 0.85 m.

The contractual specifications indicate that the land has to reach 90% or 75% of consolidation under a load which is a fill to a final level +4.8 mCD or +5.8 mCD. As the land was reclaimed to +6.5 mCD, the final settlement obtained by the Asaoka method corresponds to the final settlement under a load which is a fill (originally) to level +6.5 mCD. Therefore a correction – based on the effective stress increase – has been applied to the final settlement obtained by the Asaoka method to define the final settlement under a load which is a fill to final level +4.8 mCD or +5.8 mCD.

Results indicate that 2 months after the PVD installation, the consolidation reached the contractual specifications everywhere. The theoretical time-settlement behaviour calculated before soil consolidation has been compared to the evolution of the time-settlement behaviour recorded on site. Results show a theoretical settlement behaviour that
Table I. Geotechnical parameters used in the model.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>$\gamma_{sat}$ [kN/m$^3$]</th>
<th>$\sigma_{p}'$ [kPa]</th>
<th>$C_v$ [-]</th>
<th>$C_s$ [-]</th>
<th>$C_r$ [m$^2$/y]</th>
<th>$C_h$ [m$^2$/y]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 1 very soft</td>
<td>17.5</td>
<td>0</td>
<td>0.25</td>
<td>0.05</td>
<td>0.004</td>
<td>6.1</td>
</tr>
<tr>
<td>Layer 2 very soft to soft</td>
<td>16.0</td>
<td>0</td>
<td>0.44</td>
<td>0.09</td>
<td>0.018</td>
<td>1.2</td>
</tr>
<tr>
<td>Layer 3 stiff to very stiff</td>
<td>18.6</td>
<td>0</td>
<td>0.10</td>
<td>0.02</td>
<td>0.003</td>
<td>2</td>
</tr>
<tr>
<td>Layer 4 medium stiff</td>
<td>17.4</td>
<td>0</td>
<td>0.18</td>
<td>0.04</td>
<td>0.007</td>
<td>3.3</td>
</tr>
<tr>
<td>Layer 5 dense to very dense</td>
<td>20.0</td>
<td>0</td>
<td>0.04</td>
<td>0.01</td>
<td>0.000</td>
<td>&gt;&gt;</td>
</tr>
</tbody>
</table>

matched quite well with the recorded settlement; however the magnitude of calculated settlements was slightly higher than the recorded settlements. This is because the preconsolidation pressure was chosen to be neglected (0kPa). Therefore, the preconsolidation pressure was modified in the input of the model in order to obtain similar calculated and recorded settlements. The preconsolidation pressure was adjusted to 10kPa in all layers. With this small modification in the input values, both the settlement behaviour and the magnitude of the calculated settlements show a good fit with recordings (see Figure 10), and the final settlement obtained using the Asaoka method matches the final settlement calculated with the model.

TRIAL EMBANKMENT

In order to test the accuracy of the model under different loads, a trial embankment was built. On the top of the reclaimed area to average +6.5 mCD, 2 m of dry sand was added. The trial embankment is 2 m in height, 20 m wide and 20 m long. The settlement beacon was located in the middle of the embankment. This trial embankment has been built after installation of the PVDs as seen in Figure 11a.

During all this time, settlements were recorded. In Figure 11b, the recorded settlements are compared to the calculated settlements: 1: calculated settlement under a fill to +7 mCD but without PVD; 2: calculated settlement under a fill to +7 mCD with PVD; 3: calculated settlement when 2 m of dry sand are added with PVD). The geotechnical parameters used in the model for the calculations of the settlement are the same as presented in Table I, except for the preconsolidation pressure which is 10kPa, coming from the back-analysis results explained above. As can be seen in Figure 11b, the settlements recorded on site and settlements calculated with this model are
close. For example, 2 months after the installation of the embankment, the settlement recorded was 0.935 m and the settlement calculated was 0.926 m. The settlements recorded on site under a constant load (after installation of the embankment) were also analysed by the Asaoka method to define the final settlement. The result is a final settlement of 1.16 m. The final settlement coming from the model is 1.20 m. This trial embankment can prove that this model is quite accurate under different loads.

**POST SOIL INVESTIGATION**

Once the consolidation criteria have been reached, a post-soil investigation was realised in order to compare the evolution of geotechnical parameters before and after the consolidation process (Figure 12). Two deep boreholes were drilled close to the location of pre-soil investigation boreholes. Similar laboratory tests were performed. The results show a decrease in the moisture content and a significant increase in the shear strength especially in the 2 first layers which are softer. SPT values also slightly increase in the soft layers. It seems that most of the consolidation takes place in the two first layers (0-14m). At higher depths the difference of moisture content and shear strength values tends to diminish.

**CONCLUSIONS**

At Dinh Vu an area of 40 ha has been consolidated using PVDs (Prefabricated Vertical Drains) and surcharge preloading. Before land reclamation, a model was realised using data coming from the geotechnical survey in order to determine the design of the PVDs (spacing and depth). Settlements recorded on site have been analysed using the Asaoka method and compared to the settlement model. Settlement behaviour and magnitude of settlement calculated matched the recorded settlement rather well and the trial embankment proves that the model is accurate. The post soil investigation realised after consolidation highlights the improvement of geotechnical parameters and that it especially takes place in the two first layers. The subsoil consolidation performed at Dinh Vu Industrial Zone has reached the contractual specifications and the project was successfully completed on schedule.
**REFERENCES**


ABSTRACT

The 33.9-km-long Saemangeum Sea Dike in South Korea links Gunsan in the north to Buan in the south. As of now it is the world’s longest sea dike. Before the dike was constructed, Mangyeon River and Dongjin River discharged directly into the Yellow Sea. When the dike was completed, a 400-km² reservoir was formed and both these rivers drain into it. Future development will involve land reclamation within the formed lake for agricultural, industrial, business, residential, wetland and ecotourism purposes.

This article concerns the land reclamation works for one of the development packages: the Polder Dike that serves as a land reclamation dike during the construction period and as a flood protection dike for the longer term. The Polder Dike consists of a sandfill core with rock revetment for erosion protection on both sides of the dike. A road pavement is provided on top of the Polder Dike. For the original design of the Polder Dike rockfill berms are used to contain the sandfill core during construction of the Polder Dike. As an alternative to the original design, geotextile tubes were used to replace the rockfill berms for the construction of the Polder Dike. More than 26 km of geotextile tubes were used for this project. The geotextile tube alternative was more economical than the rockfill berm design and also helped save up to 7 months in construction time. The geotextile tube alternative was also more environmentally friendly, giving a smaller carbon footprint when compared with the rockfill berm design.

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INTRODUCTION

Saemangeum is a region where an estuarine tidal flat existed on the coast of the Yellow Sea (also known as West Sea) in South Korea. Mangyeon River and Dongjin River flowed past the Saemangeum tidal flat to discharge into the Yellow Sea. In 1991, the South Korean government announced that a sea dike would be constructed to link two headlands just south of the industrial port city of Gunsan, 270 km southwest of Seoul. Water depths along the sea dike vary from 4 m to 27 m below MSL (Mean Sea Level). Deep tidal channels are developed at three locations: south of Sinsi Island, east of Yami Island and between Duri Island and Bukgayeok Island (HR Wallingford, 2005).

The dike closing works were completed on 21 April 2006. Flow is regulated with two constructed sluice gates. The Garyeok Sluice Gate was completed in 2003 while the Sinsi Sluice Gate was completed in 2006. A navigation lock at the northern end of the Sinsi Sluice Gate is provided to allow vessel access between Mangyeon River and the Yellow Sea. The watersheds of the Saemangeum reservoir total 3,300 km². The 33.9-km-long Saemangeum Sea Dike was officially open to the public on 27 April 2010. On 2 August 2010, Saemangeum Sea Dike was certified by Guinness World Records as the longest human-made sea barrier in the world. The Saemangeum Sea Dike is 500 m longer than the Afsluitsdijk in the Netherlands, which held the record prior to that. Figure 1 shows a map of Korea and location of Saemangeum.
The Saemangeum Development Project was mooted decades ago when South Korea had to import rice owing to droughts and cold weather extremes during the 1960s through 1980s. On 16 March 2011, the Saemangeum Development Project Master Plan was announced. The Master Plan involves the creation of 400 km² of combined reclaimed land and freshwater reservoir behind the Saemangeum Sea Dike. Figure 2 shows the Saemangeum Development Project Master Plan indicating the reclamation and land use. From the 283 km² of reclaimed land, 30% would be dedicated for agricultural purposes, 15% for ecological and environmental purposes, 8% for scientific research purposes and 7% for new and renewable energy purposes.

This article concerns primarily the construction of the Polder Dike for one of the construction packages of the Master Plan, namely the Dongjin 1 Package. However, apart from the brief introduction on the Saemangeum Sea Dike and the Master Plan this case study would be incomplete without a perspective on the construction of the Saemangeum Sea Dike and its impact on the tidal and sedimentation aspects at Saemangeum.

**TIDAL AND SEDIMENTATION IMPACT OF SAEMANGEUM SEA DIKE**

The tides in the Yellow Sea are dominantly semidiurnal. Prior to the construction of the Saemangeum Sea Dike, the Saemangeum estuary was a relatively shallow macrotidal embayment with average tidal range of 5.7 m on springs and 2.8 m on neaps (Min et al. 2011). Peak tidal currents among the shores of the western coast are often 1 to 1.5 m/s and reach a maximum of 4.4 m/s in the passage off the southwest tip of the Korean Peninsula.

Choi and Lee (2003) simulated M2 tide in the Yellow and East China Seas and found the simulations to be similar to the observed tide. Min et al. (2011) conducted comprehensive modelling studies on the tidal and sedimentation regimes at Saemangeum resulting from the construction of the sea dike. Figure 3 shows the modelled residual tidal currents of M2 before and after the construction of the Saemangeum Sea Dike.

The residual tidal currents were calculated by time-integrating the modelling results and averaging the time-integrated value of one periodic M2 tide. A sizeable eddy occurring in the area between Sinsi Island and Yami Island before the completion of the dike is shown in Figure 3(a). Residual currents in the area of interest are generally below 0.1 m/s, except in tidal flats in the river estuaries and around the islands of the Gogunsam Archipelago. After the completion of the dikes, the residual currents were generally smaller, except for larger residual currents seen between the islands of the Gogunsam Archipelago and at the end of the Gunjiang waterway.

The Saemangeum region, including the huge...
the tidal regime, particularly the tidal direction, aside from preventing the seafloor off the dike from accessing sands. Such an artificial change in tidal direction resulted in the change in sediment transport conditions for the offshore surficial sands (Lee and Ryu, 2008). The NWL (Normal Water Level) and tidal flat, was shallower than 5 m in most areas except in the main waterways (Min et al. 2011). The seafloor around the Saemangeum Sea Dike is predominantly covered with sands (Lee and Ryu 2008). These sands have been found to be derived from the Mangyeon and Dongjin rivers (Lee 2010). Before the dike construction, the riverine sands were accumulated in the form of tidal sand ridges in and around the estuary. These ridges were aligned roughly in the NE–SW direction conforming to the major axis of the tidal currents at the time. The presence of the dike has largely changed the tidal regime, particularly the tidal direction, aside from preventing the seafloor off the dike from accessing sands. Such an artificial change in tidal direction resulted in the change in sediment transport conditions for the offshore surficial sands (Lee and Ryu, 2008). The NWL (Normal Water Level) and tidal flat, was shallower than 5 m in most areas except in the main waterways (Min et al. 2011). The seafloor around the Saemangeum Sea Dike is predominantly covered with sands (Lee and Ryu 2008). These sands have been found to be derived from the Mangyeon and Dongjin rivers (Lee 2010). Before the dike construction, the riverine sands were accumulated in the form of tidal sand ridges in and around the estuary. These ridges were aligned roughly in the NE–SW direction conforming to the major axis of the tidal currents at the time. The presence of the dike has largely changed the tidal regime, particularly the tidal direction, aside from preventing the seafloor off the dike from accessing sands. Such an artificial change in tidal direction resulted in the change in sediment transport conditions for the offshore surficial sands (Lee and Ryu, 2008). The NWL (Normal Water Level) and tidal flat, was shallower than 5 m in most areas except in the main waterways (Min et al. 2011). The seafloor around the Saemangeum Sea Dike is predominantly covered with sands (Lee and Ryu 2008). These sands have been found to be derived from the Mangyeon and Dongjin rivers (Lee 2010). Before the dike construction, the riverine sands were accumulated in the form of tidal sand ridges in and around the estuary. These ridges were aligned roughly in the NE–SW direction conforming to the major axis of the tidal currents at the time. The presence of the dike has largely changed the tidal regime, particularly the tidal direction, aside from preventing the seafloor off the dike from accessing sands. Such an artificial change in tidal direction resulted in the change in sediment transport conditions for the offshore surficial sands (Lee and Ryu, 2008). The NWL (Normal Water Level) and
The Polder Dike consists of a sandfill core typically with rock revetment for erosion protection on both sides of the Polder Dike. Sand is used for constructing the core of the Polder Dike because it is available in abundance at site as bottom deposits. Figure 7 shows the subsoil profile along the Polder Dike (see also Figure 6). Generally, the subsoil profile consists of between 20-m to 40-m-thick deposit of sand, with isolated lenses of clay and gravel, overlying weathered rock and bedrock. A road pavement is provided on top of the Polder Dike with elevations ranging from EL +3.7 m to EL +6.77 m. For the original design of the Polder Dike rockfill berms are used to contain the sandfill core during construction of the Polder Dike. The rockfill berms are built to above the NWL.

An alternative design using geotextile tube berms as replacement for rockfill berms was provided for. The geotextile tube berms would be constructed in two stages. The first construction stage involves a one-on-two pyramid stacking to a top level of EL -2.2 m.
The main attractiveness of the geotextile tube berm alternative is that sand is readily available in abundance at site. Since the construction of the sandfill core of the Polder Dike requires dredging of sand deposits at site, the filling of the geotextile tube with sand is a natural extension of the dredging works with little incremental cost involved.

**Geotextile Tube Analysis**

Geotextile tubes are characterised by the circumference or theoretical diameter, the length and the fabric type used for the fabrication of the tube. The theoretical diameter is defined as the circumference divided by the factor, \( \pi \). Geotextile tubes of five different theoretical diameters were used for this project, which may be made to various lengths using two different fabric types. The geotextile tube analysis was carried out using GeoCoPS (Version 3.0) software. Figure 9 shows the typical analysis output using GeoCoPS software.

Table I shows the standard tube sizes (represented by their theoretical diameter or (the original design rockfill berm is indicated).
GeoCoPS software. The tensile strength requirement for type I and type II tube fabrics are standardised at 120 kN/m and 200 kN/m respectively.

It should be pointed out that tensile strength is not the only criteria considered in the development of the geotextile tube specifications. Other mechanical performance requirements include static puncture resistance, dynamic puncture resistance and seam strength. Hydraulic performance requirements include the sand retention requirement and water dissipation requirement. Standard filtration criteria are used for determining the required fabric pore size and permeability. Durability performance requirement include UV degradation resistance. This is to cater for fabric strength reduction as a result of exposure of the geotextile tube to sunlight during construction.

Once the geotextile tube is covered with rock, UV degradation of the geotextile tube then ceases to be an issue. The complete specification for the geotextile tubes used is given in Table V. Polypropylene is specified based on historical reasons and fabric mass per unit area and thickness are specified as a quick index check on site. Mechanical and hydraulic properties can only be tested at the test laboratory but fabric mass per unit area can be easily checked on site if a simple weighing scale is available.

Table I. Standard geotextile tube sizes, dimensions and volume.

<table>
<thead>
<tr>
<th>type</th>
<th>Theoretical diameter (m)</th>
<th>Circumference (m)</th>
<th>Filled tube height (m)</th>
<th>Filled tube width (m)</th>
<th>Filled tube volume (m³/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>6.3</td>
<td>1.1</td>
<td>2.5</td>
<td>2.2</td>
</tr>
<tr>
<td>B</td>
<td>2.5</td>
<td>7.8</td>
<td>1.4</td>
<td>3.1</td>
<td>3.5</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>9.4</td>
<td>1.7</td>
<td>3.8</td>
<td>5.3</td>
</tr>
<tr>
<td>D</td>
<td>3.5</td>
<td>11.0</td>
<td>2.0</td>
<td>4.3</td>
<td>7.2</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>12.6</td>
<td>2.2</td>
<td>5.0</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Table II. Fabric type, circumferential and longitudinal tensions for various tube sizes and conditions.

<table>
<thead>
<tr>
<th>Standard tube size</th>
<th>Theoretical diameter (m)</th>
<th>Circumferential tension (kN/m)</th>
<th>Longitudinal tension (kN/m)</th>
<th>Tube fabric type</th>
<th>Fabric ultimate tensile strength (kN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>0.6</td>
<td>39</td>
<td>31</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.1</td>
<td>21</td>
<td>14</td>
<td>I</td>
</tr>
<tr>
<td>B</td>
<td>2.5</td>
<td>0.9</td>
<td>70</td>
<td>55</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.4</td>
<td>35</td>
<td>24</td>
<td>I</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>1.2</td>
<td>110</td>
<td>86</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.7</td>
<td>53</td>
<td>36</td>
<td>I</td>
</tr>
<tr>
<td>D</td>
<td>3.5</td>
<td>1.5</td>
<td>169</td>
<td>129</td>
<td>II</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0</td>
<td>79</td>
<td>53</td>
<td>II</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>1.7</td>
<td>197</td>
<td>155</td>
<td>II</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.2</td>
<td>92</td>
<td>63</td>
<td>II</td>
</tr>
</tbody>
</table>
Geotextile Tube Stacking Format

Table III shows the geotextile tube stacking format. The stacking format at a certain location along the Polder Dike is selected based on the water depth and other practical considerations.

Other Design Checks

The geotextile tube units were also checked for hydraulic stability for the 100-year return period. The stability against wave attack was checked using the significant wave height of 1.6 m with wave period of 4.1 s. The stability against flow attack was checked using a critical velocity of 0.4 m/s.

Geotechnical stability checks (see Figure 10) that included sliding, overturning, bearing capacity and global stability were conducted and found to be adequate. The minimum factor of safety adopted in design against sliding and global stability is 1.4 while that against overturning and bearing capacity is 2.

COST SAVING OF GEOTEXTILE TUBE BERM ALTERNATIVE DESIGN

Figure 11 shows the berm boundary used to compare quantities of rockfill berm with the equivalent geotextile tube berm. Within the defined boundary, it should be pointed out that the sum of rockfill and sandfill for both designs should add up to the same number. The material quantity differences for the entire Polder Dike are shown in Table IV. The cost saving of the geotextile berm alternative design over the rockfill berm original design was US$6.2 million, based on actual tender prices.

CARBON FOOTPRINT SAVING OF GEOTEXTILE TUBE BERM ALTERNATIVE DESIGN

Engineering solutions are not just compared purely on economic terms, but are beginning to be compared on environmental terms as well. Engineering solutions that protect and
have been provided by Wortelboer et al. (2012) and Ter Harmsel et al. (2013). A carbon footprint is a measure of the impact that human activities have on the environment, in particular climate change. It is the measurement of all the greenhouse gases subject of carbon footprint associated with construction projects is gaining attention worldwide.

Examples of carbon footprint assessment associated with geotextile tube applications improve the environment are increasingly favoured. Engineering solutions that have a lower negative impact (as opposed to those that have a higher negative impact) on the environment are also favoured and that includes their carbon footprint as well. The

![Figure 10. Geotechnical stability checks (adapted from Yee 2002).](image)

![Figure 11. Berm boundary to compare quantities of rockfill berm with the equivalent geotextile tube berm.](image)
Carbon Calculator Results

1. Summary Results - TenCate Geotube® System V Rockfill Berm

Project Name: Dongjin 1 Package, Saemangeum, Korea

**HEADLINE RESULTS**

- TenCate Geotube® is lower carbon by 238.196 Tonnes CO₂e

<table>
<thead>
<tr>
<th>Method</th>
<th>TenCate Geotube®</th>
<th>Rockfill Berm</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) TenCate Geotube® Results</td>
<td>214.491 Tonnes CO₂e</td>
<td>452.687 Tonnes CO₂e</td>
</tr>
<tr>
<td>(B) Rockfill Berm Results</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Carbon Footprint Results for Berm Systems

Comparative Carbon Footprint (A - B)

- = TenCate Geotube® system is lower carbon

2. Breakdown of Carbon Footprint Results for the TenCate Geotube® System

- Materials
- Transport

3. Breakdown of Carbon Footprint Results for the Rockfill Berm System

- Rocks
- Transport

Figure 12. Results of Proprietary Carbon Footprint Calculator (a) carbon footprint comparison between geotextile tube berm and rockfill berm, (b) carbon footprint of geotextile tube berm and (c) carbon footprint of rockfill berm.

The lower the carbon footprint, the less impact the construction works have on the environment.

The accumulation of greenhouse gases in the atmosphere causes global warming. There is compelling evidence that global warming is causing a rising trend in sea level. The IPCC Climatic Change 2007-Synthesis Report (IPCC 2007) reported that from 1961 to 2003, global mean sea level rose at an average rate of 1.8 mm per year. The observed sea level rise is attributed to thermal expansion as the ocean water warms and the contribution of land-based ice caused by increased melting. Over the 21st century the sea level is projected to rise by 18 to 59 cm causing present coastlines to recede. This sea level rise and higher storm surges will result in inundations that will impact currently safe hinterland. Higher incident waves anticipated from stronger winds will intensify coastal erosion.

**Carbon Footprinting Methodology**

The carbon footprint was calculated by...
collecting data from the supply chain (primary data) and combined with literature sources (secondary data). Data was collected throughout the lifecycle which covered: Production of raw materials, transport of raw materials, manufacturing of the geotextiles, transportation to final customer, use and transport to disposal.

All IPCC direct greenhouse gases (GHGs) were included in this assessment and, since carbon footprint is measured in CO2e, all were converted to CO2e using the latest IPCC (2007) global warming potentials (GWP). These GHGs include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulfur hexafluoride. This study excludes:

- Capital goods (e.g. manufacturing of vehicles, roads, buildings, machinery etc.)
- Human energy inputs to processes
- Transport of employees to and from the place of work
- Animals providing transport services
- Offsetting of emissions

The above exclusions from the carbon footprint are in line with accepted international standards (ISO 14040:2006 and ISO 14044:2006, and the PAS 2050:2011). The most recent data for primary data collection were used, covering a period of the

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Specification for tube fabric type I for type A, B &amp; C geotextile tube</th>
<th>Specification for tube fabric type II for type D &amp; E geotextile tube</th>
<th>Test results of type E geotextile tube supplied for trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polymer material</td>
<td></td>
<td>Polypropylene</td>
<td>Polypropylene</td>
<td>Polypropylene</td>
</tr>
<tr>
<td>Mass per unit area</td>
<td>g/m²</td>
<td>&gt; 550</td>
<td>&gt; 850</td>
<td>1123</td>
</tr>
<tr>
<td>Thickness</td>
<td>mm</td>
<td>&gt; 1</td>
<td>&gt; 2</td>
<td>3.5</td>
</tr>
<tr>
<td>Tensile strength (MD)</td>
<td>kN/m</td>
<td>&gt; 120</td>
<td>&gt; 200</td>
<td>204.9</td>
</tr>
<tr>
<td>Tensile strength (CD)</td>
<td>kN/m</td>
<td>&gt; 120</td>
<td>&gt; 200</td>
<td>202.8</td>
</tr>
<tr>
<td>Tensile elongation (MD)</td>
<td>%</td>
<td>&lt; 15</td>
<td>&lt; 15</td>
<td>14.8</td>
</tr>
<tr>
<td>Tensile elongation (CD)</td>
<td>%</td>
<td>&lt; 15</td>
<td>&lt; 15</td>
<td>10.5</td>
</tr>
<tr>
<td>Permeability</td>
<td>m/s</td>
<td>α x 10⁻¹</td>
<td>α x 10⁻¹</td>
<td>1.5 x 10⁻¹</td>
</tr>
<tr>
<td>CBR puncture resistance</td>
<td>kN</td>
<td>&gt; 11</td>
<td>&gt; 16</td>
<td>18.2</td>
</tr>
<tr>
<td>Drop cone</td>
<td>mm</td>
<td>&lt; 10</td>
<td>&lt; 8</td>
<td>7.2</td>
</tr>
<tr>
<td>Seam strength</td>
<td>kN/m</td>
<td>&gt; 85</td>
<td>&gt; 160</td>
<td>183.7</td>
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<tr>
<td>Pore size</td>
<td>mm</td>
<td>&lt; 0.3</td>
<td>&lt; 0.3</td>
<td>0.25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Capacity</th>
<th>Unit</th>
<th>For deployment</th>
<th>Capacity</th>
<th>Unit</th>
<th>For dredging and filling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting barge</td>
<td>1400HP</td>
<td>1</td>
<td></td>
<td>1400HP</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Flat barge</td>
<td>1900HP</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tug boat</td>
<td>650HP</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lifting crane</td>
<td>65 metric tonnes</td>
<td>1</td>
<td></td>
<td>50 metric tonnes</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Backhoe</td>
<td>0.6 m³</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dredger</td>
<td>2000HP</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anchor boat</td>
<td>280HP</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
specific. For comparison of carbon footprint savings of the geotextile tube berm alternative design over the rockfill berm original design, likewise to the cost-saving comparison, only the difference in quantities between the two berm designs are compared (see Table III). The transportation distance between the source location of the rockfill and the project site include a road journey of 50 km and a barge journey of 4 km. The transportation distance

calendar year in 2010. The period of GHG assessment (i.e., the temporal boundary) is 100 years, which is in line with PAS 2050:2011 and all global warming potential factors are based on a 100 year timeline.

A proprietary Carbon Footprint Calculator was developed for the purpose of calculating carbon footprint based on the described methodology. This proprietary Carbon Footprint Calculator was developed jointly with a leading specialist consultant on the subject of carbon footprint, Sustain Ltd in the United Kingdom, and also incorporates the principles of carbon footprint conversions according to guidelines given in DEFRA (2010).
between the manufacturing location of the geotextile tubes and the project site include road journeys of 500 km and a sea journey of 3,000 km.

For the carbon footprint of the rockfill berm original design, the energy consumptions involved in the quarrying of rock, in the transport of the rockfill, that of mechanical equipment in transferring the rock from dumper trucks onto barges and that involved in the placement of rockfill at site are determined. For the geotextile tube berm alternative design, the carbon footprints of the geotextile tubes used (based on cradle to site life cycle) and that of the sand dredging and filling works involved are determined.

In the comparison exercise, the carbon footprint of basal geotextile is not included because it is common for both options. Figure 12 shows the results of the Carbon Footprint Calculator. Figure 12(a) shows the summary for carbon footprint comparison between the geotextile tube berm alternative design and the rockfill berm original design. The total carbon footprint saving for the geotextile tube berm alternative design over the rockfill berm original design is more than 230,000 tonnes of CO2e, representing a 52% carbon footprint saving. Figure 12(b) shows the breakdown of carbon footprint results for the geotextile tube berm alternative design while Figure 12(c) shows the breakdown of carbon footprint results for the rockfill berm original design.

Figure 16. Installation of geotextile tube and formation of sandfill core of the Polder Dike begins with setting out with the GPS equipment and then (a) the laying of basal geotextile (b) laying of geotextile tube (c) attachment of sandbag to weigh down the geotextile tube (d) attaching the filling pipe to the submerged geotextile tube and finally (e) filling of the geotextile tube with dredged sand to design height.
CONSTRUCTION

Trial Installation
Prior to award of subcontract for the supply and installation of the geotextile tubes, a trial installation exercise was carried out in early June of 2012. This trial installation involved geotextile tubes of prequalified suppliers. The trial installation exercise was conducted to ensure the prequalified geotextile tubes would perform according to design and to confirm the project time saving assessment. Besides cost saving, the geotextile tube berm alternative design was expected to result in a project time saving of 10 months.

The geotextile tubes prequalified for the trial installation were also tested for conformance to project specifications at a client nominated testing laboratory. The award of the subcontract for the supply and installation of the geotextile tubes was finally based on competitive bidding subject to satisfactory site installation performance and the tested product meeting the specification requirements.

Table V shows the specifications for tube fabric types I and II and the test results of the type E geotextile tube from the winning supply contractor. The trial installation involved two lower units and an upper unit of type E geotextile tube. The length of the lower units was 55 m while the length of the upper unit was 47.5 m. Based on the trial installation, it was determined that the time required to install a type E geotextile tube of typical length of 50 m was about 9 hours.

Equipment Deployed
Table VI shows the equipment deployed for dredging, geotextile tube installation and the construction of the sandfill core. Figure 13 shows the diagram of the dredger and distribution pipes used to deliver sand for filling geotextile tube and sandfill core of Polder Dike. Figure 14 shows the diagram of the setting barge deployed for laying out the geotextile tube. Figure 15 shows the diagram of the setting barge deployed for the filling of geotextile tube.

Installation Sequence
Figure 16 shows the installation of geotextile tube and formation of sandfill core of Polder Dike. The geotextile tube installation sequence is as follows:

- Setting out using GPS survey equipment on work barge (see opening photo)
- Laying of basal geotextile layer on bottom (see Figure 16a)
- Floating out the geotextile tube (see Figure 16b)
- Attaching sandbags to loops at sides of geotextile tube to sink and weigh down the geotextile tube (see Figure 16c)
- Attaching the filling pipe to one of the fill port of the geotextile tube (see Figure 16d)
- Filling of the geotextile tube with dredged sand to design height (see Figure 16e)
- Closing of all fill ports.

The sequence is then repeated for the next geotextile tube installation. The first construction stage of the geotextile tube berm involves a one-on-two pyramid stacking of geotextile tubes. When sufficient length of the first stage geotextile tube berms have been constructed on both sides of the Polder Dike, the sandfill core is then constructed by filling in-between the parallel geotextile tube berms (see Figures 17a and 17b). The third layer geotextile tube is then installed where required before the rest of the sandfill core of the Polder Dike is constructed.

Work Progress
The construction subcontract for the supply and installation of the geotextile tubes A commenced in July 2012. On average, the time required to install type A, B, C, D and E geotextile tubes of length 62 m each are 3.5, 4.6, 5.7, 6.8 and 9 hours, respectively.

The installation of geotextile tube berm for the Polder Dike was completed in May 2013. Despite a three-month delay in works because of severe winter conditions, the geotextile tube alternative solution still resulted in a saving in construction time of 7 months when compared with the original solution using rockfill berm.

Figure 17. Left, Discharging dredged sand to form sandfill core of the Polder Dike and right, the sandfill core of the Polder Dike surfacing above water level.
CONCLUSIONS

In this case study involving the use of geotextile tubes as a replacement for rockfill for the construction of a Polder Dike for the Dongjin 1 Package in South Korea, geotextile tubes provided a number of economical and environmental advantages. The Polder Dike is made of a sandfill core with rock revetment for erosion protection on both sides of the dike. A road pavement is provided on top of the Polder Dike. The geotextile tube berm alternative design resulted in:
- a cost saving of US$ 6.2 million,
- a carbon footprint saving of more than 230,000 tonnes of CO2e or 52% over the rockfill berm original design, and
- a shortening of the overall project duration by 7 months.

REFERENCES


DEFRA (2010). “Guidelines to Defra/DECC’s GHG conversion factors for company reporting”. The Department for Environment, Food and Rural Affairs, United Kingdom.


ABSTRACT

Securing disposal fields to receive soft dredged material has become a big challenge, particularly in Japan where finding disposal fields is getting more difficult. Research to utilise soft dredged material for construction as recycled material is quite advanced in Japan. The PM-CLAY (pre-mixed clay) Method is a solidification method for soft sediment developed within this social background.

A large-scale perimeter bund was recently constructed in Asia using the PM-CLAY Method. For this project, an unprecedented volume of 3,000,000 m³ pre-mixed clay (hereafter, “PM-CLAY”) was placed at a level 30 m below sea level.

This method uses PM-CLAY (a mixture consisting of natural clay, water and cement) as a construction material, which is useful for reclamation, revetment and perimeter bunds. The PM-CLAY Method has many special features. Especially, it can produce a variety of desired materials to cope with each particular construction purpose by adjusting the water and cement balance according to the characteristics of the natural clay. As PM-CLAY consists of fluid materials, it can be used without additional soil improvement works.

In this project the perimeter bund was constructed with an inclined face of eighteen (18) degrees (1:3) by direct placing PM-CLAY without using any mold. The PM-CLAY Method also helped reduce the local procurement of construction materials at the site area as it uses PM-CLAY that is a mixture of natural clay, water and cement.

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INTRODUCTION

A large volume of soft dredged material may be obtained from dredging works such as harbour dredging. In the past such material has been disposed of in gravel disposal fields or used to fill in the ground because soft dredged material cannot be used directly as a construction material. In recent years, however, securing disposal fields to receive soft dredged material has become a big challenge, particularly in Japan where finding disposal fields is getting more difficult. In addition, research to utilise soft dredged material for construction as recycled material is quite advanced in Japan, since obtaining beach sand or pit sand that can become high-quality construction material is growing more difficult.

The PM-CLAY (pre-mixed clay) Method is a solidification method for soft sediment developed within this social background. The PM-CLAY Method has been applied in many construction works accumulating experience and extending the areas of application in Japan, but it has rarely been applied in any overseas large-scale marine construction. This report describes the outline of the PM-CLAY Method and an example of its application in large-scale perimeter bund construction work overseas.

THE PRE-MIXED-CLAY METHOD

The PM-CLAY Method is an engineering method to produce solidified disposed soil.
Construction of a Perimeter Bund Using the Pre-Mixed (PM)-Clay Method

TAKU SAITOH
graduated in 1992 from Muroran Institute of Technology, Hokkaido, Japan in the Department of Geotechnology. In the same year he began work at TOA CORPORATION. He is presently Manager of the Machinery Group, Machinery & Electric Department at TOA.

FEATURES OF THE PM-CLAY METHOD
The features of the PM-CLAY Method are summarised as follows:

- The method can solidify a large volume of cohesive soil.
- To cope with large-scale harbor construction work, the PM-CLAY vessel has nominal capacity to place solidified soil at a rate from 300 to 500 m³/hr.
- The method produces a flowing and pumpable feed material where tamping is not required.
- The PM-CLAY Method has a feature that allows the processed soil to flow and makes construction with pump feeding possible without the need of tamping since it uses cohesive soil as raw material.
- Also, since it uses cohesive soil as raw material, the artificial ground is lighter compared to that made of general ground material.
- PM-CLAY soil is lighter compared to solidified soil made from sandy soil.
- The process is applicable in a relatively narrow space. The PM-CLAY Method makes it possible to operate in a narrow work space, because there is a series of work stations; soil-gathering, production of processed soil, and placement is performed in a specialised vessel.
- Solidity and the ability of the solidified soil to flow are easily adjustable. By adjusting the amount of additional water or solidification material according to the result of the prior combination tests, solidified soil with solidity or flow ability optimal for the purpose of use can be produced.

EXAMPLES OF PM-CLAY METHOD APPLICATION
Some major applications and their effects are shown in Table I. Many of the past results relate to the application being used for landfill material for marine and inland reclaimed land, embankment levees, widening material and divider material. It can also be used as backfill material for quays and revetments because of the benefits from earth load reduction, prevention of liquefaction and achieving desired solidity.

Figure 1. Construction method of the PM-CLAY Method.
CONSTRUCTION OF LARGE-SCALE PERIMETER BUND USING THE PM-CLAY METHOD

This large-scale perimeter bund project in Southeast Asia was constructed using the PM-CLAY Method. The Project can be outlined as:

- **Volume of PM-CLAY**: about 3,000,000 m³
- **Maximum sea water depth**: -30 m (sea level)
- **Bund top elevation**: +4.5 m (sea level)

**Project features**

The main features of this project are:

1. An unprecedented volume of 3,000,000 m³ PM-CLAY was placed at a level -30 m below sea level.
2. In this project, the perimeter bund was constructed with an inclined face of eighteen (18) degrees by direct placing of PM-CLAY without using any mold.
3. The hard clay, which was the main construction material of the perimeter bund, was provided from the in-fill area in this project. The layout of main equipment for the PM-CLAY Method is shown in Figure 3.

<table>
<thead>
<tr>
<th>Application</th>
<th>Effect of the PM-CLAY Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine and inland landfill material</td>
<td>Effective use as recycled dredged material can reduce any environmental burden. Large volumes and rapid loading is possible as landfill material for large-scale filled-in ground, shortening the construction period and reducing the cost. The reclaimed land is easier to use with no need for soil improvement and no ground sinking because the material can be provided in a short period with desired solidity through the addition of solidification material. Since the material can be pumped via pipelines on the sea surface and placement underwater is also possible, land-filling can be started from any location. Also with additional strength it is easier to ensure the stability of the bank, and such.</td>
</tr>
<tr>
<td>Back-casting material or back-fill material of new or existing revetment</td>
<td>Reduction of the earth load makes it possible to reduce the size of the levee body, foundation, and sheet pile cross-section that can lead to reductions in cost and work period. The material can be used to prevent liquefaction of backfilled ground, seismic reinforcement of established structures and raising backfilled ground.</td>
</tr>
<tr>
<td>Revetment levee widening material and divider material</td>
<td>Because underwater placement is possible, levee-widening and dividers can be constructed at any location of the revetment. Also since there is no need of temporary roads and additional strength, reductions in cost and work periods may be achieved.</td>
</tr>
<tr>
<td>Surface improvement material of soft soil filled-in ground and backfill material around underwater structure</td>
<td>These materials can be used for surface improvement of soft soil filled-in ground and backfill material around underwater structures.</td>
</tr>
</tbody>
</table>

Table I. Typical application examples of the PM-CLAY Method and their effects.
Construction method of perimeter bund

The construction of the perimeter bund using the PM-CLAY method was carried out in two phases which consisted of trench placing and bund placing. PM-CLAY materials used were mainly natural clay, cement, and seawater.

• During the trench-placing phase, after completion of trenches as designed, PM-CLAY was being placed into the trench up to the seabed level. Construction above the seabed level was treated as bund placing.
• During bund-placing, a dike approximately 1.5-m high was placed on either one or both sides of the bund to prevent PM-CLAY from spilling off the bund. This method was done repeatedly until the desired shape was formed.

During the perimeter bund placing project, the perimeter bund was constructed using solidifying clay that was a comparatively difficult job when considering the characteristics of the material (locally produced clay) and requirements for the quality. If low-fluid PM-CLAY is used, and a large amount of PM-CLAY is placed at a fixed position, this causes a quality problem in the peripheral part of the PM-CLAY placement.

Therefore, PM-CLAY placement at one place at a time was limited to a certain amount and was carried out by moving the placing pipe (see Figure 4). In addition, PM-CLAY was placed by inserting the discharge port of the pipe into already placed PM-CLAY. This helps prevent separation of PM-CLAY during free fall. Figure 4 shows PM-CLAY placement. Figure 5 shows the construction overview of the perimeter bund.

Dike construction

Before construction of the bund, a dike with a height of approximately 1.5 m was constructed along the side of the PM-CLAY bund to maintain the designed bund shape and to prevent newly placed PM-CLAY from overflowing.

In this project, the dike was constructed by direct placing of PM-CLAY without using any molds. Normally, PM-CLAY was too soft to construct the dike. Therefore, the perimeter bund was placed by using stiff PM-CLAY, and
the placing pipe was accurately positioned for dike construction. After completing the dike, PM-CLAY placing was started. The placing filled up the gap in between the two dikes.

This method would be done repeatedly until the desired shape was formed. Figure 6 shows the dike construction method.

Supply of raw material clay
Placement tests using natural clay showed that the natural clay was not well mixed with the cement and seawater. Accordingly, natural clay was required to be loosened to a 3- to 5-cm slump to allow mixing well with PM-CLAY.

For improving the PM-CLAY production capacity, dredged natural clay was loosened beforehand by excavators equipped with a powerful mixing device, which were mounted on a pre-treatment vessel.

Loosened natural clay was sent to the PM-CLAY vessel. Both sides of the pre-treatment vessel allowed mooring of barges for natural clay transport. When the barge is brought alongside, the mixing bucket was lowered into the material barge and the mixing process would start (Figure 7).

Installments of PM-CLAY vessels
Construction of the perimeter bund under this project required lower fluid material than that of the solidifying clay used under the ordinary PM-CLAY method. Accordingly, two PM-CLAY vessels were constructed, which were

Figure 6. Construction of dike.

Figure 7. Clockwise: Top, the pre-treatment vessel; middle, the pre-treatment work close up; and below, the mixing device.

Figure 8. SENEI NO.17, one of two PM-Clay vessels.
When placing stiff PM-CLAY to –30 m sea level, it was important to control accurate positioning of the placing pipe and achieving the end of placing pipe level for maintaining the good quality of the PM-CLAY.

The PM-CLAY vessel was equipped with two types of placing equipment: placing pipes (Figure 9) and a distributor. PM-CLAY placing pipes are used in deeper water from –30 mCD to –5 mCD and the distributor is used in shallow water from –5 mCD to +2.5 mCD.

For improving the moving speed of the placing pipe, an automatic vessel operation system was installed on the PM-CLAY vessel to manipulate the movement of the placing pipe.

**FUTURE TASKS**

A particularly big issue amongst the problems encountered during construction work was that of obstacles contained in the natural clay. The handling of the natural clay containing a large volume of obstacles was so difficult that no effective measures could be taken using the equipment.

Fortunately, the obstacles contained in the natural clay decreased by changing the dredging site of the natural clay, but the measures for dealing with the obstacles contained in the natural clay remain a task for the future.
Facts About Seabed Intervention
An Information Update from the IADC
Available free of charge online and in print.

Subsea infrastructure installations are often exposed to high external pressures and cold temperatures. They are subject to tidal movements, currents and scour unless buried in the seabed. A structure on an irregular seabed runs the risk of spanning and overstressing. To avoid these and other risks, dredging contractors are asked to make the seabed flatter or to cover the structure with rock or concrete mattresses for protection. These interventions require high-tech vessels equipped with remotely operated underwater cameras and acoustic systems.

The ultimate goal of seabed intervention is to prevent damage to the underwater structures. When the integrity of a pipeline or cable fails, the consequences can be dramatic. The current Facts About attempts to explain just how challenging this job can be.

The Facts About series is an initiative of the International Association of Dredging Companies (IADC) to distribute up-to-date information on various maritime construction and dredging subjects. All Facts About are downloadable as a PDF at www.iadc-dredging.com. Print copies are available on request from the IADC Secretariat, info@iadc-dredging.com.

Natural Capital at Risk: The Top 100 Externalities of Business
Published by Trucost PLC.

Actions to address the risks associated with climate change and the depletion of natural resources gained momentum with the publication of the United Nations Millennium Ecosystem Assessment in 2005. This report from the TEEB (The Economics of Ecosystems and Biodiversity) for Business Coalition takes this initiative a step further.

On behalf of the TEEB for Business Coalition, Trucost, a company specialising in environmental data analysis, has undertaken a study built on TEEB’s The Economics of Ecosystems and Biodiversity in Business and Enterprise and the World Business Council for Sustainable Development’s Guide to Corporate Ecosystem Valuation.

The study ranks natural capital by impact, sector and region. Environmental impact categories known as Environmental Key Performance Indicators (EKPI) were developed by Trucost for the appraisal of businesses, sectors and regions. The top 100 environmental impacts on a global scale are ranked by sector and region. Categories include land use, water consumption, greenhouse gases, air pollution, land and water pollution and waste. For each sector in each region (region-sector), Trucost estimates the natural capital cost broken down by six EKPIs and a ranking of the top 100 costs has been derived from this. Trucost also estimates the 20 region-sectors with the highest combined impacts across all EKPIs to provide a platform. A number of specific recommendations for companies, investors, governments and for the TEEB for Business Coalition are extrapolated from this.

The report is quite exact, with tables such as “Table 5: Ranking of the 100 Region-Sectors by EKPIs with the Greatest Impact across All EKPIs When Measured in Monetary Terms” as well as a series of detailed appendices. It offers companies the means to make strategic, operational and financial decisions to develop a “natural capital-smart” approach that will lead to responsible decisions about natural capital, both for long-term sustainability and for business.

Handbook for Centrifugal Pumps and Slurry Transportation
By C.H. van den Berg
October 2013. Full colour.
Published by IHC Merwede, Sliedrecht, The Netherlands

This autumn an important new reference work was published – Handbook for Centrifugal Pumps and Slurry Transportation, written by well-known engineer C.H. (Kees) van den Berg. Van den Berg worked for many years at IHC Merwede/MTI Holland, leading its research department and also teaching at its dredge training center, the Training Institute for Dredging.

This comprehensive, highly technical book is the culmination of information gathered through years of research at IHC Merwede as well as from the works of many noted scientists such as Durand, Stepanoff, Wilson and S.E.M. de Bree. The book explains current state-of-the-art hydraulic transport technology. It describes the vital role of the pump in the entire hydraulic transportation system, and how pipeline, pump, drive and soil influence each other in a complex way. To verify physical models, dredging contractors have cooperated with field experiments worldwide. Meant as an up-to-date, illustrated reference and educational tool, the book combines years of in-depth research with hands-on, practical experience.

Available from MTI Holland (www.mtholland.com) and through the website of the Training Institute for Dredging (www.dredgetraining.com). Special arrangements are available for educational institutions. For further information enquire at info@mtholland.com.
FIRST HEMISPHERIC CONFERENCE ON DREDGING AND BUOYING  
MARCH 26-28, 2014  
BUENOS AIRES, ARGENTINA

The Inter-American Committee on Ports (CIP) of the Organization of American States (OAS) is the permanent Inter-American forum of Member States to strengthen hemispheric cooperation and the development of the port sector, with the active participation and collaboration of the private sector. The growth of the maritime traffic has resulted in the increase in the size of the ships that arrive at the ports of the Americas. Faced with this reality, many ports have undertaken ambitious projects with heavy investments in dredging to adjust the ports to the depths that require the new ships.

The CIP- OAS wants to play a key role in the announcement of these works that are being developed in many of their ports. For that reason they are supporting the First Hemispheric Conference on Dredging and Buoying. This Conference will be an excellent opportunity to gather together both public authorities in charge of ports on the continent and the various companies who are responsible for the works of dredging. These companies will exhibit their work both on technical aspects as well as on the benefits that will accrue to the different ports after the completion of the respective works. For example, there will be detailed information on the dredging works on the new Panama Canal, the waterway of the Rio Parana and Uruguay and the deepening of the track of the Paraná River navigable from Santa Fe to the north, in Argentina, the continuation of the dredging of the channel Martin García in Uruguay, the access to the port of Callao in Peru, and the navigability project for the Magdalena River, in Colombia, amongst others.

The event’s programme is being prepared by the Undersecretariat for Ports and Waterways of Argentina in coordination with the Secretariat of the Inter-American Committee on Ports of the OAS.

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SOUTHERN BALTIC CONFERENCE ON DREDGED MATERIALS IN DIKE CONSTRUCTION  
APRIL 10-11 2014  
ROSTOCK / WARNEMÜNDE, GERMANY

Rostock and the DredgDikes project consortium, together with the German Association of Environmental Engineers BWK and the German Port Technology Association HTG are organising the South Baltic Conference on Dredged Materials in Dike Construction.

The project DredgDikes  
The project DredgDikes was initiated by the University of Rostock and Gdansk Technical University to investigate the application of dredged materials, geosynthetics and different ash-composites in dike construction. The international cooperation project is part-financed by the EU South Baltic Cross-border Co-operation Programme 2007-2013.

Papers in English for both oral and poster presentation will be presented on the following topics:

- geochemical and geotechnical characterisation of dredged materials and composite materials containing dredged materials;  
- legal background for the beneficial use of dredged materials in geotechnical applications;  
- utilisation of fine-grained organic dredged materials in geotechnical applications;  
- utilisation of composite materials containing dredged materials in geotechnical applications;  
- geosynthetic solutions to improve dredged materials used in geotechnical application;  
- special aspects and case studies for the use of dredged materials in dike constructions.

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www.dredgdikes.eu

33RD PIANC WORLD CONFERENCE  
JUNE 1-5, 2014  
SAN FRANCISCO, CA, USA

The PIANC World Conference will have the theme “Navigating the New Millennium” and participants and presenters are sought from every continent regarding best practices and innovation. Those submitting an abstract should choose the theme/topic below that is most appropriate:

- Global Navigation Issues of the 21st Century  
- Ports and Maritime Navigation  
- Inland Waterway Systems  
- Environmental Issues – Towards Working with Nature  
- Dredging  
- Urban and Recreational Waterfronts

The PIANC 2014 Congress will include: Technical Short Courses, Plenary Sessions, Concurrent Technical Session Tracks, Industry
IADC SEMINAR ON DREDGING & RECLAMATION
MARCH 31-APRIL 4, 2014
NOVOTEL, BRISBANE, AUSTRALIA.

For the first time ever IADC is happy to present its International Seminar on Dredging and Reclamation in Brisbane, Australia. Aimed at (future) decision makers and their advisors in governments, port and harbour authorities, off-shore companies and other organisations who have to execute dredging projects, the IADC has organised the Seminar at numerous venues often in co-operation with local technical universities. Since 1993 this week-long Seminar has been successfully presented in Delft, Singapore, Dubai, Buenos Aires, Abu Dhabi, Bahrain and Brazil. As is appropriate to a dynamic industry, the Seminar programme is continually updated. In addition to basic dredging methods, new equipment and state-of-the-art techniques are explained.

To optimise the chances of the successful completion of a project, contracting parties should, from the start, fully understand the requirements of a dredging project. This five-day course strives to provide an understanding through lectures by experts in the field and workshops, partly conducted on-site in order to give the “students” hands-on experience.

Highlights of the programme are:
Day 1: Why Dredging? The Need for Dredging/Project Phasing
Day 2: What is Dredging? Dredging Equipment/Survey Systems (includes a site visit)
Day 3: Production of various types of dredgers
Day 4: Preparation of a Dredging Contract, Reclamation, Tender, Cost Pricing
Day 5: Contracts

An important feature of the Seminars is a site visit to a dredging project being executed in the given geographical area. This gives the participants the opportunity to see dredging equipment in action and to gain a better feeling of the magnitude of a dredging operation. Each participant receives a set of comprehensive proceedings with an extensive reference list of relevant literature and, at the end of the week, a Certificate of Achievement in recognition of the completion of the coursework. Please note that full attendance is required for obtaining the Certificate of Achievement.

Group discount
The fee for the week-long seminar is AUD 4,400 (€ 3,100 inclusive VAT). The fee includes all tuition, seminar proceedings, workshops and a special participants’ dinner, but excludes travel costs and accommodations. Assistance with finding hotel accommodation is available. A Group Discount of AUD 400 (€ 280 per person) will be offered to groups and organisations wishing to register two or more delegates.

Other Upcoming IADC Seminars in 2014:
- June 23 to June 27, Delft, The Netherlands (in co-operation with UNESCO-IHE)
- October 27 to October 31, Singapore (in co-operation with the National University of Singapore).

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WEDA 34/TAMU 45 CONFERENCE
JUNE 15-18, 2014
FAIRMONT ROYAL YORK,
TORONTO, ONTARIO, CANADA

In June 2014 the Western Dredging Association and Texas A&M will be holding its next Annual Western Hemisphere Dredging Conference at the Fairmont Royal York in Toronto, Canada, one of the most renowned hotels in Canada since 1929.

Exhibition, Technical Tours, Networking Events, Accompanying Persons Cultural Tours. The Congress is held every four years and is open to members and non-members.

For further information contact:
• Email: pianc@usace.army.mil

With the theme, “Expanding the Dredging World”, delegates will experience another interesting and educational technical programme that will promote the exchange of knowledge in fields related to dredging, navigation, marine engineering and construction, as well as the enhancement of the marine environment.

Authors are invited to submit one page abstracts (<300 words) due January 15, 2014. The Conference will begin with a pre-conference tour of Toronto, a city that has a multi-cultural population of people from over 200 countries.

For further information contact:
Larry Patella
WEDA Executive Director
• Email: weda@comcast.net
www.westerndredging.org
Terra et Aqua is an English language journal, articles must be submitted in English.

Articles should be original and should not have appeared in other magazines or publications. Articles in the form of case studies, research reports, and short, concise articles that present and discuss new ideas or experiences are welcome.

Students and young professionals are encouraged to submit articles based on their research.

Articles in Terra et Aqua may be translated to other languages with the author’s permission.

Authors are requested to provide in the “Introduction” an insight into the drivers (the Why) and the impact (the Where) of their project. The “Introduction” should include a brief discussion of the project, the challenges encountered, and the benefits achieved. The “Introduction” should be concise and to the point.

In the case of articles that have previously appeared in conference proceedings, permission is required for publication. Authors are kindly requested to consult the editor.

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