ABSTRACT

The Lach Huyen Port Project involves the construction of a new deep sea port for the northern region of Vietnam. Part of the project involves the construction of a 15.6 km long highway linking the Hanoi-Haiphong Expressway at the Tan Vu Interchange on the mainland to Lach Huyen Port on the eastern side of Cat Hai Island. The highway includes the 5.4 km long Lach Huyen Bridge with 84 spans supported by piers across the sea. Except for the presence of a deeper navigational channel, the seabed generally consists of intertidal flats. The top most soil layer with thickness of about 6 to 9 m consists of very soft organic sandy silty clay. The maximum tidal range can be as high as about 4 m. Bridge construction works require heavy machinery for installation of foundation piles, construction of bridge piers and launching of bridge sections. Soft ground and tidal conditions are the two main construction challenges imposed by the site environment. To allow bridge construction works to be carried out on dry land expeditiously, two construction works platforms with approximate width of 26 m and 3.9 km in total length were reclamed along the alignment of the bridge. About 27 km of geotextile tubes were used as reclamation bund, segmentally stacked up to five layers high over intertidal soft clay deposits for the construction of the platforms. Sand was dredged offshore and transported to the site using a combination of barging and hydraulic pumping for the construction of the platforms. A portion of 1.5 km of the bridge was constructed by the offshore method using work barges. A 1 km long channel along the alignment of the bridge was dredged to increase water depth sufficiently to allow the work barges to operate without any low tide interruptions. Geotextile tubes were used to construct the containment bund of the 620,000 m³ dredged sediment containment facilities. Upon completion in 2017, Lach Huyen Bridge will be the longest sea-crossing bridge in Vietnam.

INTRODUCTION

Hai Phong Port and Cai Lan Port are the two ports currently serving the northern region of Vietnam. It is estimated that demand for containerised cargo in the northern region of Vietnam will be 42 million tons in 2015, which will further increase to 59 million tons by 2020 in tandem with economic growth, well beyond the combined capacities of the two existing ports. Also, in recent years, there is a growing trend in of shipping companies increasing their orders for large-container vessels to meet customers’ needs and to reduce cost. In order to upgrade the functions of the northern region of Vietnam and to become an international distribution centre, it is necessary to develop a port that has sufficient depth to accommodate large container vessels. The new Lach Huyen Port located on the eastern side of Cat Hai Island was planned and designed as a deep sea port to handle larger vessels and to cope with the projected growth of demand in cargo volume.

Package 6 of the overall Lach Huyen Port Infrastructure Construction Project, involves the construction of a new 15.6 km long highway linking the Hanoi-Haiphong Expressway at the Tan Vu Interchange on the mainland to Lach Huyen Port. The proposed Tan Vu-Lach Huyen Highway provides a shortened link between the Hai An District and Cat Hai Island. The travel time between Tan Vu Interchange and Lach Huyen Port will be reduced from the 2011 estimate of 2.5 hours to about 15 minutes with the completion of the new highway (see Figure 1). The highway includes the 5.4 km long Lach Huyen Bridge with 84 spans supported...
by piers. The bridge site spans across the combined estuary of Bach Dang River and Cam River. The Lach Huyen Bridge consists of the 4.4 km western approach bridge, the 0.5 km main bridge (over the navigational channel) and the 0.5 km eastern approach bridge. The western abutment of Lach Huyen Bridge is located just south of Dinh Vu Development Area while the eastern abutment is located at the western shore of Cat Hai Island. Upon completion in 2017, Lach Huyen Bridge will be the longest sea-crossing bridge in Vietnam. The bridge will be 16 m wide accommodating four lanes for vehicles and two safety corridors while the approaches will be 29.5 m wide for traffic design speed of 80 km per hour (see Figure 2).

SITE CONDITIONS AND CONSTRUCTION CHALLENGES

Geology
The area consists of Quaternary coastal sediments overlying a Pleistocene land surface, and represents the Holocene marine transgression and regression. Up until 6000 years ago, the sea rose to around or above its present elevation, converting the Pleistocene terrestrial landscape to a Holocene tidal landscape of tidal flat, channel and mangrove environments. The sea level lowered at around 4000 years ago that triggered a switch in the dominant sedimentary processes, allowing floodplain sediments to be deposited increasingly seawards.

Climate
Haiphong has a tropical climate with high humidity and temperatures. The average annual rainfall is 1760 mm (over 76 years of observations). The rainy season covers the months from May to October and accounts for about 80% of the total annual rainfall. The dry season is from November to March. The months from October to December are particularly foggy. For about twenty days of the year the visibility is less than one km, occurring mostly during October to December. Generally, the winds in the Haiphong area are gentle. Winds of 1 to 4 m/s account for 60% of occurrences while winds over 10 m/s account for only 2% of occurrences. According to wind records in Hon Dau Observatory the dominant directions are the east, south-east, south and north. The area is occasionally subjected to typhoons, typically from June to September. The strongest measured winds induced by typhoons reached 51 m/s on August 21, 1977.
treatment ground conditions at the Bridgestone plant. There are four distinct layers of the deposits. The soft clay layers have low bearing capacity and excessive settlement characteristics. The first layer consists of very soft organic sandy silty clay with thickness of about 6 to 9 m and undrained shear strength of about 5 kN/m². The second layer consists of soft to very soft clay with fine sand with thickness of about 6 to 8 m and undrained shear strength of about 10 kN/m². Below that is an approximately 4.5 m layer of stiff to very stiff clay with gravel. The fourth layer generally consists of medium stiff clay. Figure 3 shows the typical foundation soils and the moisture contents and undrained shear strengths before and after ground improvement.

Construction Challenges
The bridge construction works require heavy machinery for installation of foundation piles, construction of bridge piers and launching of bridge sections. The soft ground and tidal conditions are the two main construction challenges imposed by the site environment. The soft ground conditions create difficulty for machinery to work on. Also, a significant portion of the bridge alignment is under shallow water either part of the day or at all times. Except for the navigation channel under the main bridge, there is insufficient water depth for access for work barges during all tidal conditions. Both land-based and offshore construction methods are employed along different segments of the bridge alignment (see Figure 4). To allow bridge construction works to be carried out on dry land expediently two construction works platforms were reclaimed along the alignment of the bridge. The platforms with approximate width of 26 m and 3.9 km in total length were built to RL 2.55 m. A portion of 1.5 km of the bridge was constructed by the offshore method using work barges. A 1 km long channel along the alignment of the bridge was dredged to increase water depth sufficiently to allow the work barges to

Tides, Waves and Currents
Haiphong has the diurnal tidal regime i.e. one high tide and one low tide every day. The spring tide/neap tide cycle is 14 days with a maximum tidal range of nearly 4 m. The highest high water level (HHWL) is at +2.55 m. The mean high water level (MHWL) is at +1.97 m. The mean low water level (MLWL) is at -1.67 m. The mean tide level (MTL) is at +0.15 m. The Hon Dau Station records of 2006 to 2008 show that 60% of waves come from directions of the quadrant of the east to the south. Wave heights of more than 1 m occur about 9% of the time. The significant wave height, Hs, is 1.7 m with a peak wave period of 11.16 s. The tidal wave propagates from south to north with mean velocities between 0.2 to 0.3 m/s. The maximum ebb-tidal current is 0.6 m/s while the maximum flood-tidal current is 0.5 m/s.

Foundation
The subsoil in the area generally consists of very thick alluvial and marine clay deposits above a dense to very dense sand/gravel foundation. The Dinh Vu Development Area was reclaimed from the sea. At the new Bridgestone tyre plant close to the project site, prefabricated vertical drains and surcharging were used to improve the soft ground. Mountulet et al. (2013) documented in great detail the pre-treatment and post-

Figure 3. Typical foundation soils at Bridgestone tyre factory, located near the Lach Huyen Bridge project site (after Montulet et al. 2013).
operate without any low tide interruptions.

**GEOTEXTILE TUBE AND CONSTRUCTION ADVANTAGES**

**Definition**
Geotextile tube is defined as “a large tube [greater than 7.5 feet (2.3 m) in circumference] fabricated from high strength, woven geotextile, in lengths greater than 20 linear feet (6.1 m)”, according to GRI Test Method GT11: Standard Practice for “Installation of Geotextile Tubes used as Coastal and Riverine Structures”.

**Installation**
Geotextile tubes used in coastal and riverine applications are typically filled hydraulically with sand. Also, filling ports are geotextile sleeves sewn into the top of the geotextile tube into which the discharge pipe is inserted (see Figure 5). They are typically laid at the final intended location prior to filling. Initially, the filling ports at the extreme ends of the geotextile tube are utilised while those in-between are temporarily closed. One end is for the pumping in of sand slurry while the other end is for water pressure relief and discharge. In this way, the sand slurry will flow from one end to the other of the geotextile tube gradually depositing sand along the way. It may be necessary to move the filling point in order to achieve more even filling of the geotextile tube. After completion of filling, the port sleeves are closed and attached to the geotextile tube in a manner sufficient to prevent sand loss and movement of the sleeve by wave action.

**Design Methodology**
From a technical standpoint the geotextile tube needs to fulfill the following (Yee, 2002):

- **Internal stability**
  - The geotextile used to fabricate the tube, including seams and closure, need to withstand the stresses encountered during the filling process (commonly referred to as the tensile strength requirement)

- **External stability**
  - The sand filled geotextile tube structure should be stable against wave and current attacks (commonly referred to as the hydraulic stability requirements)
  - The sand filled geotextile tube structure should be stable against sliding, overturning, bearing and global slip failures (commonly referred to as the geotechnical stability requirements (see Figure 6)

- **Durability and robustness**
  - The geotextile should withstand installation stresses and perform as required over the lifespan of the design (commonly referred to as the survivability requirement)

One of the critical stressing moments for a geotextile tube is during the pumping of slurry into the geotextile tube. Design software like GeoCoPS (Leshchinsky & Leshchinsky, 1995) and SOFTWIN (Palmerton, 1998) that will

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**Figure 5. Schematic of filling of geotextile tube with sand slurry.**

**Figure 6. Geotechnical stability checks (adapted from Yee, 2002) (a) sliding (b) bearing (c) overturning (d) global.**
would sail to the unloading jetty for transfer to the sand stockpile depot or to a specific work area where the sand is needed. From the stockpile depot, sand is pumped through about 3 km of HDPE pipeline with a diameter of 300 mm to the temporary storage yard. A booster pump is used midway to maintain sufficient pressure throughout the pipeline. When required, sand is pumped from the temporary storage yard for the installation of geotextile tube and reclamation of works platform (see Figure 4).

**Technical Properties of Geotextile Tube**

The project specification for geotextile tube is based on tensile strength and sand tightness requirements. The geotextile tube fabric should have tensile strength of more than 204 kN/m, tested according to JIS L 0221 or ASTM D4595 or equivalent test methods. The geotextile tube supplied to the project is fabricated from high tenacity woven polypropylene fabric. Typically, the geotextile tube has tensile strengths ranging between 215 to 225 kN/m in the fabric machine direction and between 230 to 250 kN/m in the fabric cross direction. The pore size, O90, of the geotextile tube fabric ranges typically between 0.3 to 0.35 mm, tested according to ISO 12956. The strength retention after 500 hours of exposure in the Xenon Arc accelerated UV testing chamber, tested according to ASTM D4355, is in excess of 90%. Although this is generally considered very high, nonetheless, the geotextile tubes are expected to remain fully exposed up to five years as the issue of UV resistance and survivability of the geotextile became an important issue early on in the project.

**Works Platform**

To allow bridge construction works to be carried out on dry land expeditiously two construction works platforms with approximate width of 26 m and 3.9 km in total length were reclaimed along the alignment of the bridge. Figure 7 shows the typical cross section of the construction works platform constructed using geotextile tubes as reclamation bunds. This construction technique is used for the first time in Vietnam but has been used widely in Korea in the past (Yee et al. 2007; Yee & Choi, 2008). The geotextile tubes were hydraulically filled with sand dredged offshore. About 27 km of geotextile tubes were used as reclamation bund, segmentally stacked up to five layers high over intertidal soft clay deposits for the construction of the platforms. The geotextile tubes used for the construction of the reclamation bund comprised of circumferences of 4.6, 6, 7.5 and 9.5 m, with typical lengths of 50 m. The works platform together with the geotextile tube reclamation bund will be embedded within a future land reclamation that would enlarge the Dinh Vu Development Area to approximately double its current size (see Figure 1). The installation of
Geotextile tubes began in July 2014 and was completed by December 2014.

**Dredged Sediment Containment Facility**

The dredging works of the 1 km access channel were carried out using front arm excavators placed on a flat bottom barge. The dredged sediment is pumped to the dredged sediment containment facility. Geotextile tubes were used to construct the perimeter bund of the containment facility. The bund was constructed using geotextile tube with standard length of 15 m and circumference of 9.5 m. The bottom level consists of two units placed side by side and a top unit is then placed centrally above that. The containment facility has a storage capacity of more than 600,000 m³. Figure 8(a) shows the cross section of the dredged sediment containment facility.

**Temporary Sand Storage Yard**

Geotextile tubes were used for containment and erosion protection of the temporary sand storage yard. This storage yard functions as a buffer storage of sand needed to install the geotextile tubes and as reclamation fill in the construction of the works platform and that needed the installation of geotextile tubes for the construction of the dredged sediment containment facility (see Figure 8(b) and Figure 9(a)). This storage yard was constructed ahead of the other geotextile tube installations. One of the geotextile tubes at the temporary sand storage yard was used for the purpose of a trial installation exercise. This monitored full scale geotextile tube trial installation will be described in the following section.

**TRIAL INSTALLATION AND MONITORING WORKS**

**Purpose**

The full scale geotextile tube trial installation was conducted on 15 August 2014. The purpose of conducting the full scale geotextile tube trial installation and monitoring works was firstly to test out the proposed installation methodology for the project as well as the suitability of selected materials and equipment. Secondly, the exercise allowed the determination of the fill material properties achieved through the installation methodology which then served as a benchmark during the installation proper. Finally, this trial installation exercise also provided the opportunity for the construction team to gain experience.

**Materials**

According to the Unified Soil Classification, the fill material is a well graded medium sand (SW) with a d₉₀ value of 0.38 mm, tested according to AASHTO T 27 (see Figure 10). The specific gravity of the sand was 2.66, tested according to ASTM C128. The maximum dry density (MDD) is 1.63 g/m³ at the optimum moisture content (OMC) of 16.4, tested according to AASHTO T 180. The geotextile tube used in the trial was a full size prototype of length 50.5 m and circumference 7.5 m.

**Equipment**

The primary equipment for the geotextile tube trial installation included amphibious excavator for feeding sand into steel tank and general works, bull dozer for moving sand, submersible sand pump (6 inches, 22 kW), submersible water pump (6 inches, 11 kW), generator set (220 kVA), steel tank for sand...
Levelling of ground (this will not be a necessary step for actual works)

Driving guide posts into the ground (see Figure 12a)

Laying of geotextile over prepared ground and anchoring edges with sand bags (see Figure 12b)

Laying out geotextile tube over geotextile

Position steel gantry frame at location of intended filling positions (see Figure 12c)

Securing geotextile tube to guide posts; ropes are used to tie the loops at side of geotextile tube to the guide posts (see Figure 12c)

Placing submersible water pump into position

Placing steel tank in position

Connecting flexible hose from water pump to steel tank

Placing submersible sand pump into steel tank

Connecting sand slurry delivery pipeline from steel tank to intended filling positions with filling elbow

Hanging filling elbow from steel gantry frame (see Figures 12d, 12e and 12f)

Initiating the filling process by starting the submersible sand pump and water pump; the rate of feeding of sand should be controlled

Switching filling position when required

**Tube Height and Geometry Survey**

Figure 13(a) shows the level survey of datum prior to the filling of the geotextile tube. Figure 13(b) shows the level survey of the top of a geotextile tube during the filling process. Figure 13(c) shows the digging of a small trench to obtain access to midway of the tube bottom for the purpose of level survey. Figure 13(d) is a cross-section diagram of the filled geotextile unit showing the mode of

![Figure 10. Gradation curve of sand used for filling of trial installation geotextile tube (AASHTO T 27).](image)

![Figure 11. Results of modified Proctor test (AASHTO T 180).](image)

![Figure 12. Installation of geotextile tube (a) installing guide posts (b) laying base geotextile (c) geotextile tube laid out (d) start of filling process (e) filling in progress (f) completion of filling.](image)
MODELING THE LATERAL RESTRAINT PHENOMENON

The Fully Fluid Model

The method described by Timoshenko (1959) is based on the equilibrium of an encapsulating flexible shell filled with pressurised slurry, resulting in the tensile force being constant over the entire circumference of the geotextile.

measurement of levels and tube width. Figure 14 shows the survey of top of geotextile tube level above datum with time. Measurements are taken at three locations; Point 1 is 5 m from the north end of the tube, Point 2 is in the middle of the tube and Point 3 is 5 m from the south end of the tube. Table 1 summarises the levels, tube heights and widths for all three survey points. The one day consolidated geotextile tube height ranges from 1.36 m to 1.44 m with an average value of 1.4 m. The tube width is however consistent at 3.3 m, irrespective of the final tube height.

Figure 14. Level of top of geotextile tube versus time.

<table>
<thead>
<tr>
<th>Survey point</th>
<th>Top of tube level just after pumping shutdown minus level prior to filling (m)</th>
<th>[A] Top of tube level 1 day after pumping shutdown minus level prior to filling (m)</th>
<th>[B] Level of top of tube minus level of bottom of tube (m)</th>
<th>[B-A] Ground settlement at mid-section of tube (m)</th>
<th>Width of tube (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.46</td>
<td>1.30</td>
<td>1.44</td>
<td>0.14</td>
<td>3.31</td>
</tr>
<tr>
<td>2</td>
<td>1.28</td>
<td>1.27</td>
<td>1.36</td>
<td>0.09</td>
<td>3.33</td>
</tr>
<tr>
<td>3</td>
<td>1.42</td>
<td>1.42</td>
<td>1.41</td>
<td>-0.01</td>
<td>3.31</td>
</tr>
</tbody>
</table>

Table 1. Level and tube width survey results

Field Density Test

Table 2 shows the results of the field density test carried out just after installation and three days after installation. The soil sampling points correspond to the filling ports beside the survey points listed in Table 1. The compaction ratio achieved three days after installation ranges from 85 to 89% with an average of 87%.

Table 2. Results of field density test (AASHTO T204)

<table>
<thead>
<tr>
<th>Sampling point</th>
<th>Test done just after installation (15 Aug 2014)</th>
<th>Test done 3 days after installation (18 Aug 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture content (%)</td>
<td>Dry density (m)</td>
</tr>
<tr>
<td>1</td>
<td>23.3</td>
<td>0.949</td>
</tr>
<tr>
<td>2</td>
<td>25.6</td>
<td>0.931</td>
</tr>
<tr>
<td>3</td>
<td>24.8</td>
<td>1.000</td>
</tr>
</tbody>
</table>

MODELING THE LATERAL RESTRAINT PHENOMENON

The Fully Fluid Model

The method described by Timoshenko (1959) is based on the equilibrium of an encapsulating flexible shell filled with pressurised slurry, resulting in the tensile force being constant over the entire circumference of the geotextile.
the membrane shell. Consequently, the pressure in the geotextile tube is low, except during the final stages of filling of the geotextile tube. It should be noted that the deposition in pipeline flow is undesirable while deposition inside the geotextile tube is a prime objective. During initial stages of filling the geotextile tube is relatively flat due to the low pressure regime inside it. As more material is pumped into the tube, it will increase in height and narrow down in width as long as the material remains relatively fluid in nature, which is the basis of most of the currently available design tools. However, as deposition progresses inside the geotextile tube, this deposited layer will start acting as a lateral restraint to progressive narrowing down of the tube width associated with further filling of the geotextile tube. This happens when the deposited layer acts as saturated sand rather than as a sand slurry. The saturated sand layer provides passive resistance against attempt to progressive narrowing down of the geotextile tube width associated with further filling of the geotextile tube. Figure 16(a) shows the geometric response under a fully hydrostatic filling condition while Figure 16(b) shows the

Sand Flow Hydraulics and Deposition

The basic principles of pipeline delivery of sand slurry are best explained in stages, starting with the pumping of clean water. In order to move the water through the pipeline, pressure is required and this is provided by the dredging pump. At the pipe outlet there is velocity but no pressure, thus pressure loss is encountered along the length of the pipe. The water head or pressure is potential energy that is expended in overcoming the frictional resistance offered by the pipeline wall over the entire length of the pipe as a result of creating velocity of the pumped water. Pressure loss increases in direct relation to water velocity and inverse relation to pipe diameter. For the pipeline to deliver sand slurry, the pressure loss curve deviates from that of pumping water. Figure 15 shows a typical pipe pressure versus flow velocity relationship of water and sand slurry in pipeline flow.

Firstly, the pressure/velocity curve trends above that for pumping water, due to higher density of sand slurry over water. The curve can also be subdivided into three flow types i.e. homogenous pipe flow, layer or depth graduated pipe flow and partial upper section flow over lower section deposited solids. When the pressure is high enough a homogenous pipe flow condition will occur. When pressure is reduced, the flow velocity reduces to a point when the solids start concentrating near the bottom of the pipe with flow partly in suspension and partly rolling along the bottom of the pipe. When pressure is further reduced a point is reached when the solids start to settle at the bottom of the pipe. A critical point is then reached whereby only the upper section of the pipe allows slurry flow and consequently leads to flow resistance and increase in pressure loss. If this is allowed to continue, this would lead to a blocked pipeline when the energy requirements exceed the capacity of the pump.

The sand slurry flow inside the incoming pipeline and inside the geotextile tube has a few key differences. Firstly, the circumference of the pipe is basically very small when compared with that of the geotextile tube. Secondly, the pipe section is generally rigid and remains relatively the same all the time while the geotextile tube section is flexible and the geometry changes with time or stage of deposition. Also, the geotextile tube cross sectional area increases with increase in tube height. Thirdly, the walls of the pipe is impermeable and thus there is no pressure loss resulting from seepage through the pipe walls. However, the membrane shell of the geotextile tube is permeable and there is pressure loss as a result of seepage through the membrane shell. Consequently, the pressure in the geotextile tube is low, except during the final stages of filling of the geotextile tube. It should be noted that the deposition in pipeline flow is undesirable while deposition inside the geotextile tube is a prime objective. During initial stages of filling the geotextile tube is relatively flat due to the low pressure regime inside it. As more material is pumped into the tube, it will increase in height and narrow down in width as long as the material remains relatively fluid in nature, which is the basis of most of the currently available design tools.

However, as deposition progresses inside the geotextile tube, this deposited layer will start acting as a lateral restraint to progressive narrowing down of the tube width associated with further filling of the tube. This happens when the deposited layer acts as saturated sand rather than as a sand slurry. The saturated sand layer provides passive resistance against attempt to progressive narrowing down of geotextile tube width associated with further filling of the geotextile tube. Figure 16(a) shows the geotextile tube geometrical response under a fully hydrostatic filling condition while Figure 16(b) shows the
The effect of the lateral restraint phenomenon on the geotextile tube geometrical response. Yee et al. (2010) reported observation of this lateral restraint phenomenon during the installation of geotextile tube with a circumference of 15.7 m were filled with coarse sand. When the lateral restraint phenomenon takes hold, further tube height gain is largely due to fabric elongation in response to tension build up in the fabric. The pressure inside the geotextile tube will gradually build up as the flow sectional area is reduced with the progress of deposition. This will continue until a stage when very little gain in geotextile tube height is achieved over time with the pressure increasing exponentially. A point will then be reached when the structural integrity of the geotextile tube will be compromised.

**Modelling of Geotextile Tube with Lateral Restraint Phenomenon using DMEM**

The graphical solution using Discrete Membrane Elements Method (DMEM) was developed by Yee (2012) for the analysis of the fully fluid filled geotextile tube. The paper (Yee, 2012) may be referred to for full formulation details. The solution using DMEM agrees almost perfectly with GeoCoPs, SOFTWIN and Geotube® Simulator programmes currently available for the analysis of the fully fluid filled geotextile tube. However, currently available softwares are unable to model the lateral restraint phenomenon in design.

DMEM was used to incorporate the lateral restraint phenomenon in design. The modelling of geotextile tube with lateral restraint phenomenon involves two analytical stages. The first analytical stage involves using DMEM to analyse the stage geometry under fully fluid filled condition. The width of the tube in stage 1 analysis is assumed as the lateral restrained width (see Figure 17). In stage 2 analysis the top fabric portion is taken as a flexible canopy with its ends attached to two fixed points (Point S1 and Point S2) uplifted hydraulically by pressurised slurry. The sand deposit in the bottom section is assumed to be fully bonded with the geotextile tube fabric that is in contact. The geometry of this bottom section and the tensions developed in the membrane in contact with this bonded and laterally restrained bottom section remains constant and unaffected by the second stage filling. DMEM is also used for the second analytical stage. The appropriate boundary conditions that reflect the lateral restraint phenomenon i.e. horizontal distance between Point S1 and Point S2 is kept constant and the top arc length between Point S1 and Point S2 elongates proportionately to further increase in pressure of the slurry at the top of tube, \( P_t \).

**DISCUSSIONS**

**Analysed and Measured Tube Geometry**

Figure 18 shows the surveyed points at Point 3 of the monitored trial installation geotextile tube (see Figure 14) compared against the DMEM analysed geometries according to the following analyses:

- fully fluid filled condition without fabric extensibility
- fully fluid filled condition with fabric extensibility
- lateral restraint condition with fabric extensibility

All the analysed upper third tube profiles agreed very well with the surveyed points. However, the lower third tube profiles obtained from the fully fluid condition analyses (for both with and without fabric extensibility) did not agree well with the surveyed points. The analysed tube overall geometry agreed well with the surveyed
Inflation Refusal Height

Looking at Figure 14, it should be noted that during the pumping process tube height increased steadily initially but began slowing down after the tube reached about one metre in height. When the tube reached about 1.3 m it was increasingly more difficult to achieve further height increase. Inflation height refusal may be defined as the state whereby very little tube height increase is seen even at relatively high tube pressures. In an attempt to understand why this is taking place the relationship between tube height and tube pressure is studied.

Figure 19 shows the plot of tube height, $h$, versus pressure at top of tube, $P_t$, from the analyses using DMEM. It can be seen that the analysis with fully fluid filled condition (irrespective of whether fabric extensibility is considered or ignored) generally overestimates the inflation refusal height. Figure 14 shows the inflation refusal height detected in the field trial to be about 1.3 to 1.4 m. Figure 19 shows that a tube height of over two metres can be achieved for the analysis with fully fluid filled condition but when tube restraint phenomenon is taken into account the tube height increase with tube pressure will be very small over the range of tube height of 1.2 to 1.4 m. The analysis with lateral restraint phenomenon and fabric extensibility accounted for thus seems to predict an inflation refusal height that agrees better with reality.

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CONCLUSIONS

A case study involving the use of geotextile tubes for the construction of the longest sea crossing bridge in Vietnam has been presented. A monitored full scale geotextile tube trial installation was conducted before major construction took place. The geometry of the monitored geotextile tube deviated from the tube geometry derived assuming a fully fluid filled condition and ignoring fabric extensibility, an approach adopted by available design software. Such design software also tends to overestimate the inflation refusal height. A solution using DMEM that can account for lateral restraint phenomenon and fabric extensibility has been presented. The solution predicted a tube geometry and inflation refusal height that agreed well with the monitored geotextile tube.

REFERENCES


