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GEOTEXTILE CONTAINMENT AND DEWATERING OF CONTAMINATED SEDIMENTS IN CHINA

T. W. Yee[1], L. Ding[2], L.K. Lim[3] and Z.Y. Wang[4]

ABSTRACT

This paper describes different examples of use of geotextile containment solutions for disposal of contaminated sediments in China. The first project is located in Hong Kong SAR. Capital dredging was carried out for the Wanchai Development Phase II Project. Contaminated sediments were dredged from the site at North Point, placed into large geotextile containers and dropped using a split bottom barge at East Sha Chau confined contaminated mud pits. The second project is located in Kunming, Yunnan Province. Maintenance dredging of Caohai part of Lake Dianchi was carried out. Geotextile tubes were used to contain and dewater dredged contaminated sediments to form the containment dikes of two sludge lagoons. The third project is located in Tianjin Eco-City involving the dredging of a 3.0 km^2 wastewater impoundment lake that has been receiving wastewater discharges from nearby domestic, agricultural and industrial sources since 1976. The lake remediation effort involved remedial dredging works. A geotextile tube dewatering facility was constructed to contain and dewater dredged contaminated sediments from the lake. This dewatering facility was later capped and planted over to form a lakeside landscaped mound.

Keywords: Geotextile containers, geotextile tubes, contamination, sludge, confined marine disposal.

INTRODUCTION

Dredging involves raising material from the bottom of a water-covered area to the surface. Dredging is generally divided into three main groups: capital dredging, involving the creation of new facilities such as a harbour basin, a navigational channel, a lake, or an area of reclaimed land for industrial, residential purposes; maintenance dredging, involving the removal of sediments from lakes, basins or channel beds to maintain navigability; and remedial dredging, primarily to remove contaminated material from a specific location. Dredged contaminated sediments require special management and disposal techniques.

China is a contracting party to the Convention on the prevention of marine pollution by dumping of wastes and other matter, 1972 (London Convention 1972) which came into effect for the country on 14 December 1985 (Bray, 2008). On 29 September 2006, China ratified the 1996 Protocol to the London Convention 1972. On 12 June 1997 China gave notification that the London Convention 1972 will apply to Hong Kong SAR (Special Administrative Region) with effect from 1 July 1997. However, there is no harmonization of standards within the country in some aspects. One example refers to the classification of sediment quality or degree of contamination.

This paper documents three recent case studies that provide a snap shot of the current practice of using geotextile containers and geotextile tubes to contain and dispose of dredged contaminated sediments in China. Figure 1 shows the location of these three case studies.

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[1] Global Manager – Reinforcement & Geosystems, TenCate Geosynthetics Asia, 14 Jalan Sementa 27/91, Seksyen 27, 40400 Shah Alam, Selangor, Malaysia, T: +60-12-208-2205, Fax: +60-3-5192-8573, Email: tw.yee@tencate.com.

[2] Environmental Applications Manager, Ten Cate Industrial Zhuhai Co., Ltd., South of Nangang West Road, Gaolan Port Economic Zone, Zhuhai 519050, Guangdong, China, T: +86-186-8888-7656, Fax: +86-756-886-1610, Email: l.ding@tencate.com.

[3] Technical Manager, TenCate Geosynthetics Asia, 14 Jalan Sementa 27/91, Seksyen 27, 40400 Shah Alam, Selangor, Malaysia, T: +60-12-278-4363, Fax: +60-3-5192-8573, Email: lk.lim@tencate.com.

[4] Sales Manager, Ten Cate Industrial Zhuhai Co., Ltd., South of Nangang West Road, Gaolan Port Economic Zone, Zhuhai 519050, Guangdong, China, T: +86-139-1128-6222, Fax: +86-10-6568-6629, Email: e.wang@tencate.com.

Figure 1. Map showing three case study project sites in China.

GEOTEXTILE CONTAINMENT SOLUTIONS

Geotextile containment solutions have been successfully applied to manage and dispose of contaminated sediments in projects internationally, e.g. Lawson (2008), Yee et al. (2006). The general goal of geotextile containment solutions is prevention or minimization of leakage of contaminants to the environment during processing, transit to and at the final disposal site. Geotextile containment solutions involve the use of large geotextile containers and geotextile tubes to contain and possibly dewater dredged sediments. Figure 2(a) shows the dropping of geotextile container filled with sediments while Figure 2(b) shows the containment and dewatering of sediments using geotextile tube.

(a) **(b)**

Figure 2. Geotextile containment solutions (a) geotextile container drop (b) geotextile tube dewatering application.

A geotextile container is essentially a very large pillow shaped bag tailored to fit the hopper of a split bottom barge. The hopper of the barge also serves as a filling formwork. When the geotextile container is filled with dredged sediments up to the designed volume, it is then sealed on site. The barge then sails to the dump site where the geotextile container is dropped into water by the opening of the bottom gate of the barge. Success is measured by the absence or lack of water contamination during its fall through the water column and impact with the seabed. This means the geotextile container should be designed using fabrication (fabric, seams and closures) that will not leak or leach contaminated sediments and has sufficient strength to survive the installation process.

A geotextile tube applied dewatering a dewatering application is essentially a flexible tubular containment vessel with a filtering external surface that effectively drains water but retains solids within. Dewatering is a process operation used to reduce moisture content of sediments for a few reasons; reduction of volume to reduce cost of transportation and landfilling, reduction of excess moisture to increase the calorific value and processing cost during incineration, etc. Effectiveness is measured by percentage solids capture, dewatering rate and achievable solids content of dewatered material. Effluent water quality is also a measured success criteria, especially when in a proposed application where there is no further water treatment prior to the effluent water being released. Conventional dewatering techniques include mechanical dewatering (centrifuges, belt presses, etc.) which require high capital investment cost and natural dewatering (drying beds and sludge lagoons) which require large area of land and can be very time consuming. The performance of natural dewatering techniques is subject to the weather and the exposed sludge can emit foul odor as well as attract airborne vectors which are negative factors to the environment. Geotextile tube dewatering technology has the advantages of being able to handle very large sludge volumes, achieving very high solids capture rate, requiring low capital investment and the sludge is effectively concealed from the environment.

Figure 3 shows the typical examples of geotextile containment solutions being applied for contaminated sediments placement at sea and on land. The choice of product depends on the application objectives and method of installation involved.

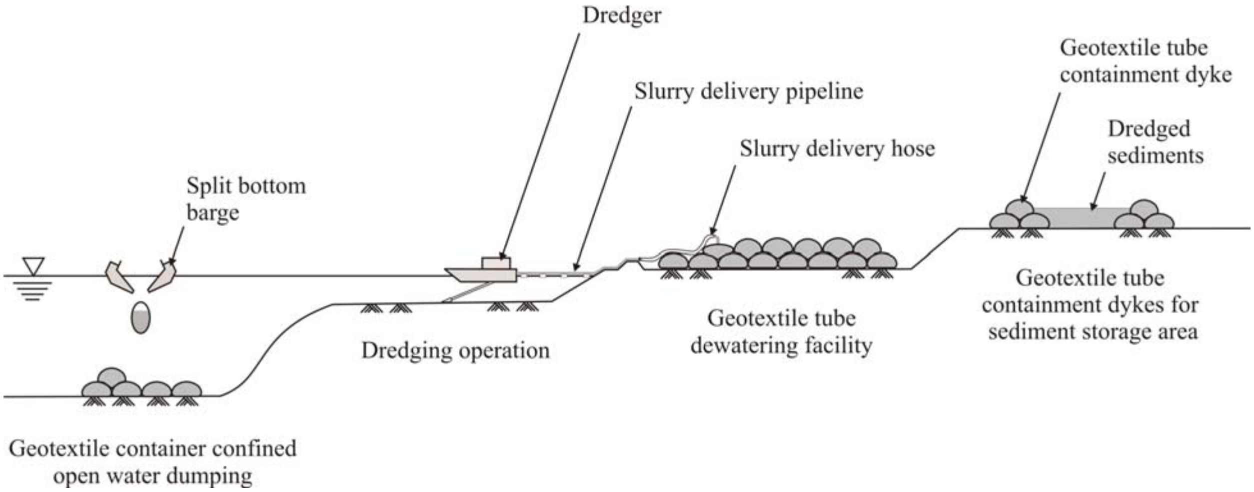


Figure 3. Geotextile containment solutions for dredged contaminated sediments.

WANCHAI DEVELOPMENT PHASE II, HONG KONG

The sediment classification system used in Hong Kong between 1992 and 2001 classified dredged sediments into three categories based on the level of contamination by seven heavy metals. If the sediments contained one or more of the listed heavy metals with contamination levels within Class C limits, they have to be sent to East Sha Chau confined contaminated mud pits for disposal.

New Management Framework

In January 2002, the Hong Kong Government introduced a new management framework for dredged sediment disposal (ETWB 2002). This new framework complies with the 1996 Protocol to London Convention 1972. Table 1 shows the sediment quality criteria for the classification of sediment in Hong Kong. The sediment is classified into 3 categories (Category L, Category M or Category H) based on its contamination levels.

Besides chemical testing of heavy metals to determine contamination levels, Category M and Category H sediments must now undergo biological screening. Figure 4 shows the flow chart of the new management framework for dredged sediment disposal in Hong Kong. For Category H sediment that fails the biological screening tests, it is then classified as Type 3 material and will require pre-treatment or special disposal.

Table 1. Sediment quality criteria for the classification of sediment (ETWB 2002).

Contaminants	**Lower Chemical Exeedance Level (LCEL)**	**Upper Chemical Exeedance Level (UCEL)**
Metals ***(mg/kg dry wt.)***		
Cadmium (Cd)	1.5	4
Chromium (Cr)	80	160
Copper (Cu)	65	110
Mercury (Hg)	0.5	1
Nickel (Ni)*	40	40
Lead (Pb)	75	110
Silver (Ag)	1	2
Zinc (Zn)	200	270
Metalloid ***(mg/kg dry wt.)***		
Arsenic (As)	12	42
Organic-PAHs ***(μg/kg dry wt.)***		
Low Organic Weight PAHs	550	3160
Low Organic Weight PAHs	1700	9600
Organic-non-PAHs ***(μg/kg dry wt.)***		
Total PCBs	23	180
Organometallics ***(μg TBT/l in interstitial water)***		
Tributyltin*	0.15	0.15

* The contaminant level is considered to have exceeded the UCEL if it is greater than the value shown.

Special Disposal Trial, 2003

Figure 5(a) shows the conventional disposal method of unconfined open water dumping. This method results in spreading and dissipation of sediments as it falls through the water column. As a result contaminants are released into the water environment and may be carried down current to impact areas away from the dumping area as well. Figure 5(b) shows the special disposal method of geotextile container confined open water dumping. This method isolates the contaminated sediments from the water column thus preventing release of contaminants into the water environment.

The special disposal method adopted for Type 3 material in Hong Kong involved the use of geotextile containers to encapsulate the contaminated sediment during disposal at East Sha Chau dumping site. The geotextile container technology is not new but as it has not been applied in Hong Kong before field trials were carried out in 2003 to determine the optimum handling method under local conditions (Cheek and Yee 2006). This special disposal method should prevent the loss of contaminants to the marine environment during disposal to be adjudged a success. During the geotextile container drop water quality measurements were carried out in the vicinity as well as down current of the drop area to detect any increase in levels of water pollutants and contaminants over the baseline. Polystyrene balls were added during the placement of dredged sediment into the geotextile container to detect leak of contaminated sediment during fall through the water column and impact with the seabed.

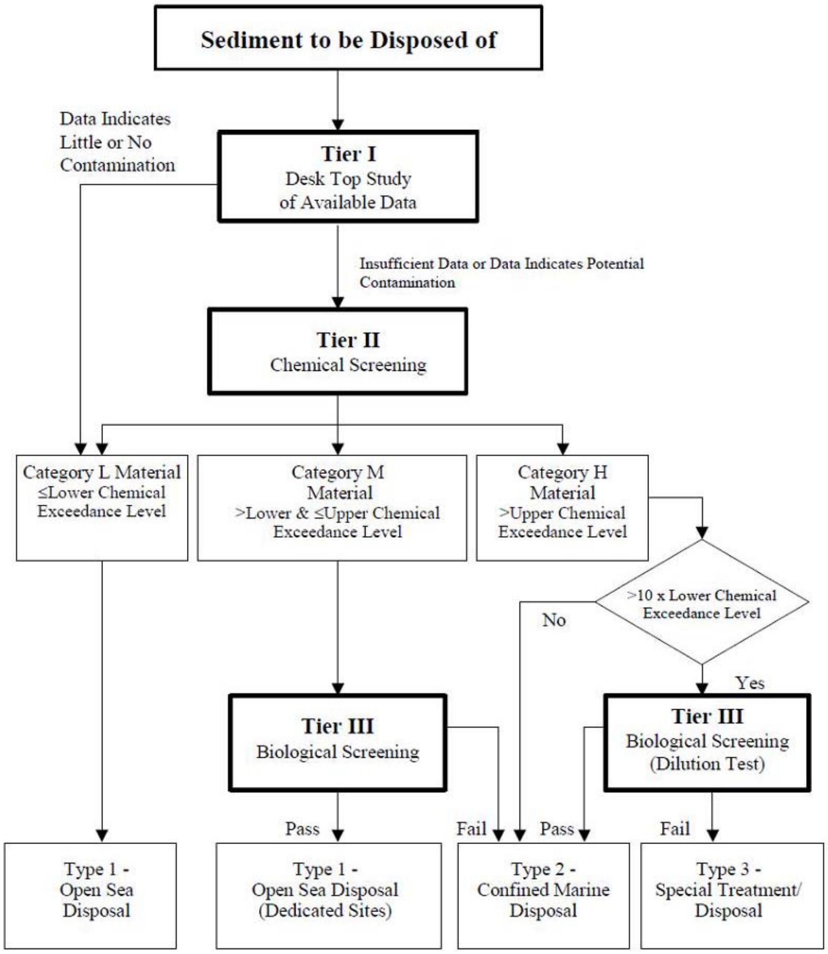


Figure 4. Flow chart of management framework for dredged sediment disposal in Hong Kong (ETWB 2002).

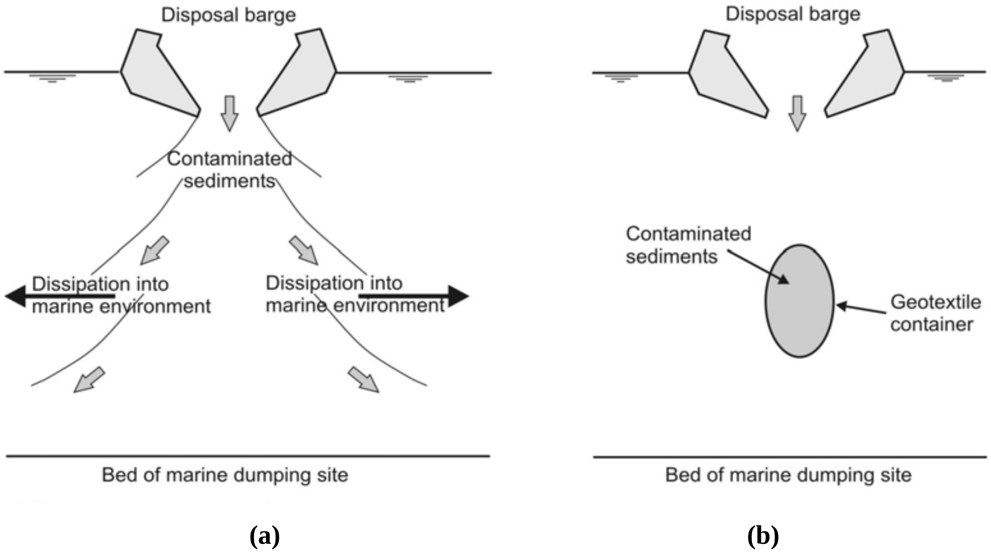


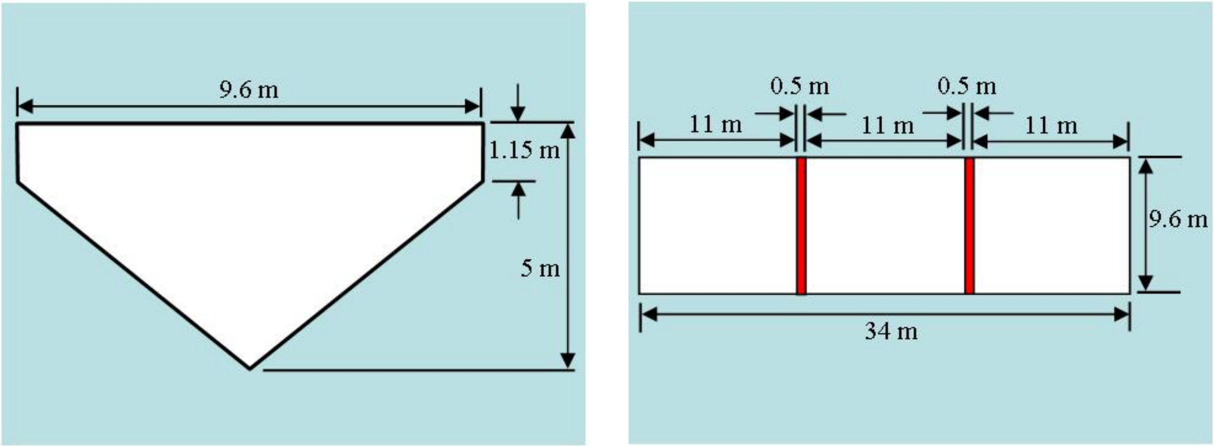
Figure 5. Marine disposal methods for contaminated sediments (a) conventional disposal by unconfined open water dumping (b) special disposal by geotextile container confined open water dumping (adapted from Lawson 2008).

Typical split bottom barges in Hong Kong have hopper holding capacities of about 1000 m^3. These were felt to be too large for the purpose intended. Geotextile containers of two sizes (600 m^3 and 300 m^3) were tested. Barge modifications included installation of longitudinal bulkheads along the full length of each side of the hopper, such that the width of the hopper was reduced. These longitudinal bulkheads also provided for safe working platforms along each side of the hopper. The resulting reduced hopper dimensions gave an effective 600 m^3 holding volume. For the 600 m^3 geotextile containers, the barge was further modified by installing transverse bulkheads. The geotextile containers were fabricated using composite fabric. Two versions of composite fabric were tested; one had a tensile strength of 120 kN/m while the other had a tensile strength of 200 kN/m). The geotextile containers fabricated using composite fabric with tensile strength of 120 kN/m experienced difficulties. The geotextile containers fabricated using composite fabric with tensile strength of 200 kN/m and seam strength of 140 kN.m were adjudged a success based on water quality monitoring and divers' inspection which found no sign of rupture or other damage to the geotextile container on the seabed.

Geotextile Containers for Wan Chai Development Phase II Project, 2011

The Wan Chai Development Phase II Project required disposal of about 3500 m^3 of Type 3 material using special disposal method. The material was dredged from North Point dredging site and sent to East Sha Chau for disposal (see Figure 6). The split bottom barge adopted had a hopper length of 34 m, width of 9.6 m and depth of 5m along the center longitudinal of the barge (see Figure 7(a)). The hopper was partitioned into three equal portions of 11m length using transverse bulkheads of thickness 0.5 m to create three equal sub-compartments each with a holding capacity of about 300 m^3 (see Figure 7(b)).

Figure 6. Location of North Point Dredging Site and East Sha Chau Contaminated Mud Pits.



(a) (b)

Figure 7. Barge hopper diagram (a) cross section (b) plan view.

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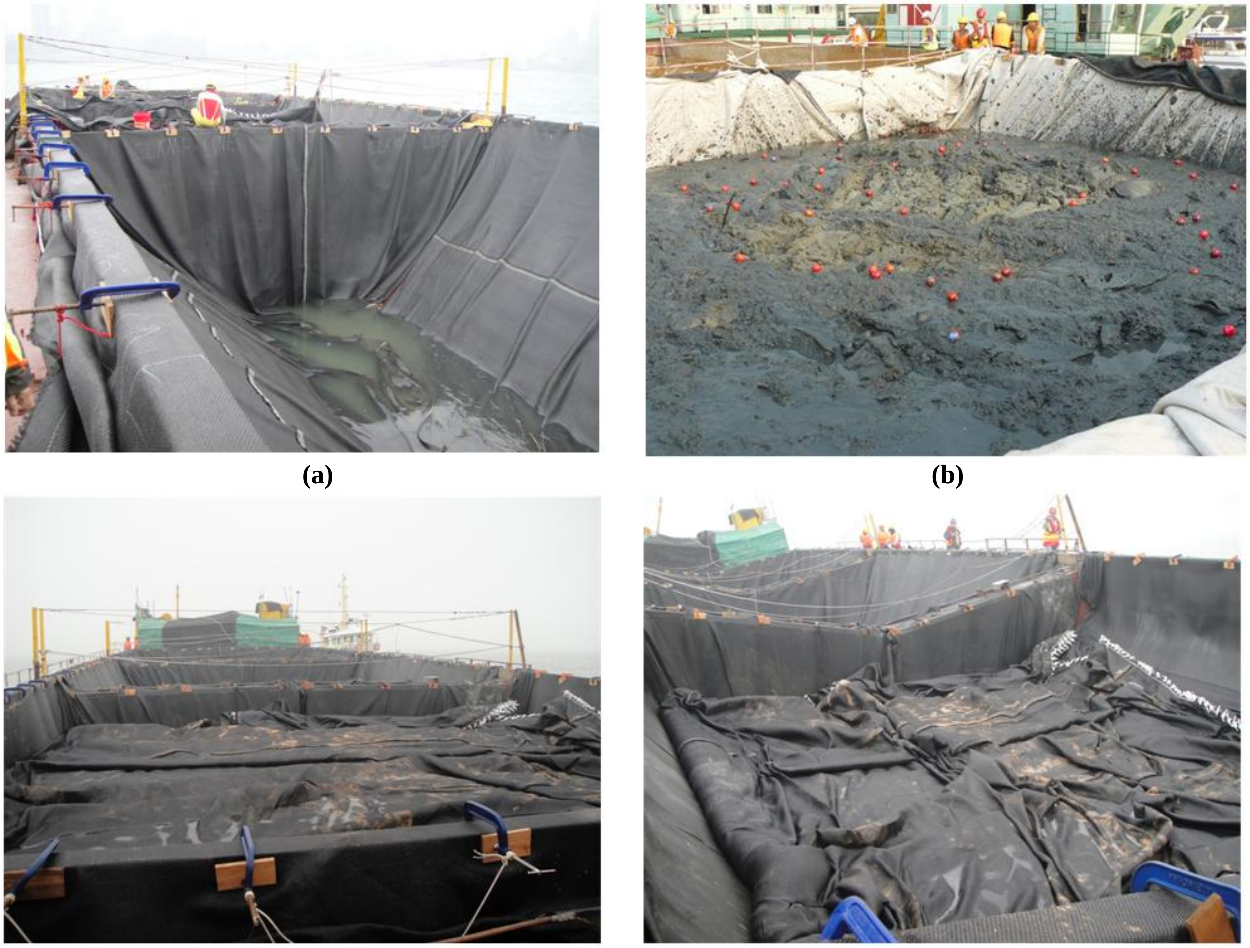
The installation commenced by placing slip sheets, with tensile strength of 120 kN/m in both machine and cross directions, clamped along the coaming of the barge hopper (see Figure 8(a)). The slip sheets were placed to protect the geotextile container during the geotextile container exit from the barge. Three geotextile containers were deployed simultaneously. The geotextile containers were lifted into the barge hopper and secured at the coaming of the barge hopper using G-clamps. Contaminated sediment was dredged from the seabed at North Point dredging site using clamp shell. The dredged material was then placed into the geotextile containers. The geotextile containers were filled to about 70% of the barge holding capacity or about 210 m^3 for each geotextile container. Red polystyrene balls were placed on top of the dredged sediments before closure on site (see Figure 8(b)). If any rupture develops in the geotextile containers during fall and impact with seabed, the polystyrene balls would escape and float to the surface. Closure of the containers was done in two stages. Firstly the two inner flaps were laced together using 6 mm diameter rope continuously for soil tightness. Then the two edges of the geotextile container were closed using rope knots at 150 mm centers for strength to prevent rupture. After closure the split bottom barge was then towed to the East Sha Chau contaminated mud pits for disposal (see Figure 8(c) and 8(d)).



(a) **(b)**

(c) **(d)**

Figure 8. Geotextile container for disposal of Type 3 contaminated sediments (a) barge hopper lined with slip sheet (b) geotextile container filled with contaminated sediments (c) geotextile container ready for release (d) geotextile container during the process of release from the barge.

A total of 17 units of geotextile containers were dropped between late December 2010 and end February 2011. No rupture was detected for all 17 units dropped. This was evidenced from the fact that no polystyrene balls were found floating on the sea surface during and after dropping the geotextile containers. Water quality measurements carried out in the vicinity as well as down current of the drop area detected no spike in levels of water pollutants and contaminants over the baseline data. The success of this project has reinforced the suitability of geotextile container confined disposal of contaminated sediments as the special disposal method for Type 3 material in Hong Kong.

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CAOHAI DREDGING PROJECT, LAKE DIANCHI, KUNMING

Formed about 3.2 million years ago, Lake Dianchi is an ancient tectonic lake located in Yunnan Province of China. At 1886 m above sea level, it is the largest lake in Yunnan and sixth largest freshwater lake in China. There are more than 20 rivers draining into Lake Dianchi. The lake is divided into two parts by a barrage. North of the barrage is Caohai (or sometimes referred to as the inner lake) while south of the barrage is Waihai (or sometimes referred to as the outer lake). Caohai has a surface area of 7.5 km^2 with an average depth of less than 2 m while Waihai has a surface area of 292 km^2 with an average depth of 4.4 m. The total lake volume is about 1.5 billion m^3 and Waihai accounts for 99% of that. The lake is part of the Jinsha River (an upper tributary of the Yangtze River) drainage basin. At Haikou Town on the southwestern part of Lake Dianchi, water drains out through Tanglangchuan River which then joins other rivers in the North before finally heading east and eventually draining into the Pacific Ocean. Figure 9 shows the map of Lake Dianchi and surrounding areas. The average annual rainfall in the area is between 0.8 m to 1.0 m with 90% of that falling during the months of May to October. The average annual evaporation is between 1.9 m to 2.1 m (Jin et al. 2006).

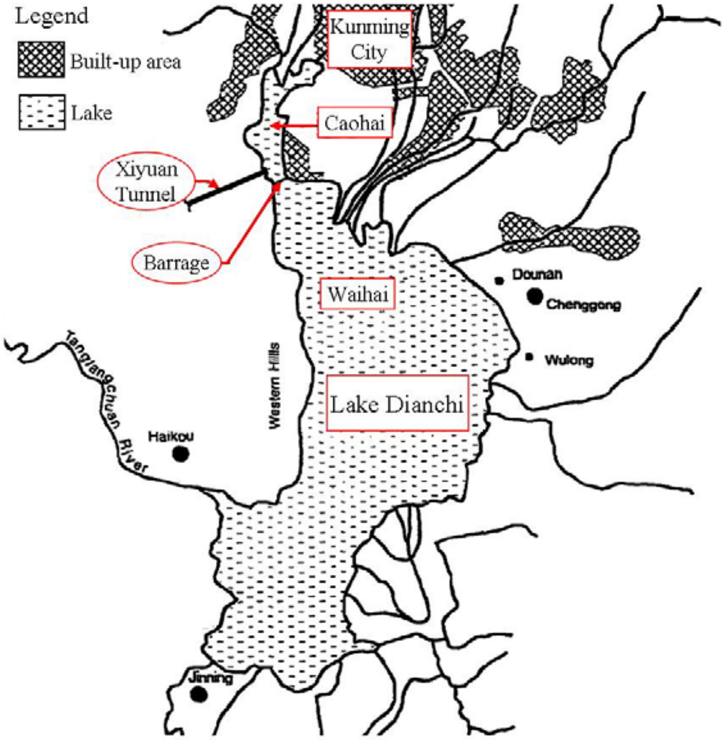


Figure 9. Map of Lake Dianchi and surrounding areas

Water Quality Classification

China uses a water quality classification system based on water use function (see Table 2). Yang et al. (2008) proposed the assessment criteria of surface water quality of lakes (see Table 3), based on selected parameters listed in the Chinese National Standard, GB3838-2002: Environmental quality standards for surface water.

Table 2. Water quality classification system (YIEP 1996).

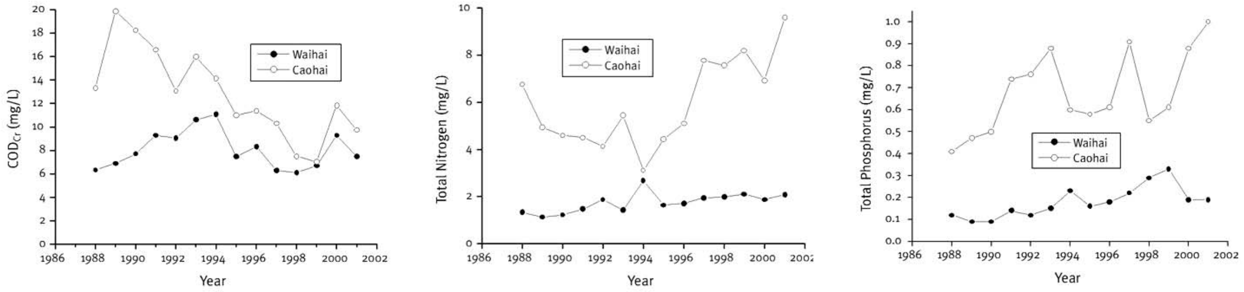
Classification	Water Use Function
I	National Nature Protection Area
II	Domestic Potable Water Source – Grade I protection area, precious fish and fish culture zone
III	Domestic Potable Water Source – Grade II protection area, general fish and bathing areas
IV	Industrial Water Use and Recreation
V	Agricultural and general amenity use

Table 3. Assessment criteria for surface water quality of lakes (Yang et al. 1996).

Items	**Surface water quality classification**				
	Class I	**Class II**	**Class III**	**Class IV**	**Class V**
Water temperature (^oC)	Maximum week increase ≤ 1; Maximum week decrease ≤ 2				
pH	6 ~ 9				
DO *(mg/l)*	Saturation ≥ 90%	≥ 6	≥ 5	≥ 3	≥ 2
COD_{Mn} *(mg/l)*	≤ 2	≤ 4	≤ 6	≤ 10	≤ 15
COD_{Cr} *(mg/l)*	≤ 15	≤ 15	≤ 20	≤ 30	≤ 40
BOD_5 *(mg/l)*	≤ 3	≤ 3	≤ 4	≤ 6	≤ 10
TN *(mg/l)*	≤ 0.2	≤ 0.5	≤ 1.0	≤ 1.5	≤ 2.0
NH_3.N *(mg/l)*	≤ 0.15	≤ 0.5	≤ 1.0	≤ 1.5	≤ 2.0
NO_2.N *(mg/l)*	≤ 0.06	≤ 0.1	≤ 0.15	≤ 1.0	≤ 1.0
TP *(mg/l)*	≤ 0.01	≤ 0.025	≤ 0.05	≤ 0.1	≤ 0.2
Chlorophyll a	≤ 0.001	≤ 0.004	≤ 0.01	≤ 0.03	≤ 0.065
Transparency *(m)*	≥ 15	≥ 4	≥ 2.5	≥ 1.5	≥ 0.5
Escherichia coli (l^{-1})	≤ 200	≤ 2000	≤ 10000	≤ 20000	≤ 40000

Eutrophication, Sedimentation and Toxification

Lake Dianchi is probably the most hypereutrophic lake in the world (Yang et al. 2008). Long known as the "Pearl of the Plateau", Lake Dianchi was in oligotrophic to mesotrophic condition in early 1950s. Rapid population growth (3.1 million in 2005 compared with 1.5 million in 1980) and economic development in the Lake Dianchi drainage basin has placed severe pressures on the lake. In the early 1960s the water of Lake Dianchi was classified as Class II. In the early 1970s the water of Lake Dianchi was classified as Class III but has now deteriorated to worse than Class V (Lu et al. 2005). The water transparency in the Caohai part was more than 2 m in the 1950s. The water in certain areas of Lake Dianchi, especially in the Caohai part, currently has a pea-soup green color with a water transparency of less than 0.5 m (Jin et al. 2006). The water quality in Caohai is generally poorer than the water quality in Waihai (see Figure 10).



(a) **(b)** **(c)**

Figure 10. Concentrations in Lake Dianchi from 1988 to 2002 (a) COD (b) TN (c) TP (adapted from Jin et al. 2006 and He & An 2001)

When it was first formed, Lake Dianchi was much larger with a surface area of over 1000 km^2 and water depth of more than 50 m (Jin et al. 2006). Although natural changes led to a gradual decrease in area and volume, changes in the land use over the last 60 years have increased the rate of erosion in the Lake Dianchi drainage basin. Since the 1950s the mean rate of surface erosion in the drainage basin is estimated at 0.38 million m^3 per annum.

Until the first wastewater plant was built in 1990, over ninety percent of Kunming's wastewater was released untreated directly into or through sewers into canals and rivers that ended up flowing into the lake. Manufacturing industries have contributed to the deterioration of Lake Dianchi. Kunming City and its suburbs host over 150 major industrial enterprises which include machine building, metallurgy, textile, food processing, chemicals and building materials. As with water quality, the degree of heavy metal contamination of lake bottom sediments is also more severe in Caohai than in Waihai. Table 4 shows the summary of abiotic characteristics of Caohai and Waihai of Lake Dianchi current for 1993 (YIEP 1993). By international standards the sediments at Caohai would be classified as highly contaminated.

The total phosphorus and total nitrogen contents listed in Table 4 agree well with those in Figure 5. The phytoplankton biomass increased a million fold between 1950s and 1990s. The chlorophyll-a concentration reached 320 μg/l at Caohai and 80 μg/l at Waihai by year 2000 (Jin et al. 2006).

Table 4. Summary of abiotic characteristics of Caohai and Waihai (YIEP. 1993).

Variable	unit	Caohai	Waihai
Transparency (SD)	m	0.37	0.68
Total phosphorus	mg/l	0.42-0.97	0.07-0.14
Total nitrogen	mg/l	3-7	1-2
Chlorophyll-a	mg/l	100-130	15-40
Water depth	mg/l	1-2	3-4(10)
Cu (sediment)	mg/kg	360-714	34-446
Pb (sediment)	mg/kg	661-1000	28-66
Cd (sediment)	mg/kg	42-80	0.4-3.36
Hg (sediment)	mg/kg	1.0-1.4	0.1-0.35
As (sediment)	mg/kg	267-332	13-43

Construction of the barrage dividing Caohai and Waihai together with Xiyuan Tunnel, completed in mid 1990s was an effort to improve the condition of Waihai. The water from Caohai was prevented from entering Waihai thereby reducing the stress on Waihai. Instead this more heavily polluted water is diverted using Xiyuan Tunnel to a water treatment plant prior to discharge into Jinsha River. The construction of this barrage however meant Caohai would experience greater siltation. Therefore regular maintenance dredging of Caohai would become a permanent feature in future. Figure 11 shows the barrage separating Caohai and Waihai (note the pea-soup green color of the lake water).

Figure 11. Aerial photo of the barrage separating Caohai (left) and Waihai (right).

Geotextile Tube Containment Dike

In 2009 a contract was awarded to dredge 0.5 m of the lake bottom of Caohai. Two sludge lagoons were constructed to contain and dewater the dredged sediments; one at Fubaotang and one at Liuyuan on the shores of Caohai. Figure 12 shows the typical cross section of the geotextile tube containment dike. The geotextile tubes were filled with dredged slurry to a specific height and then left to dewater resulting in a consolidation in the tube height. This was repeated over several cycles until the geotextile tube reached the design height and the solids within attaining the desired consistency. As the geotextile tube was filled with slurry, initially the tube has a tendency to roll over the sides. Sand bags were used to form partial height side berms to prevent the geotextile tube from rolling over its sides. The geotextile tubes used have a circumference of 15.4 m. The length of the geotextile tubes were standardized at 40 m, although some were shorter to accommodate bends and corners.

A total of 107 units were used at Fubaotang while another 79 units were deployed for Liuyuan sludge lagoon. Figure 13 shows the geotextile tube dike construction works at Fubaotang. Figure 14 shows the geotextile tube dike construction works at Liuyuan. The dredged sediments were allowed to settle and dry out before they were removed to a landfill for permanent disposal.

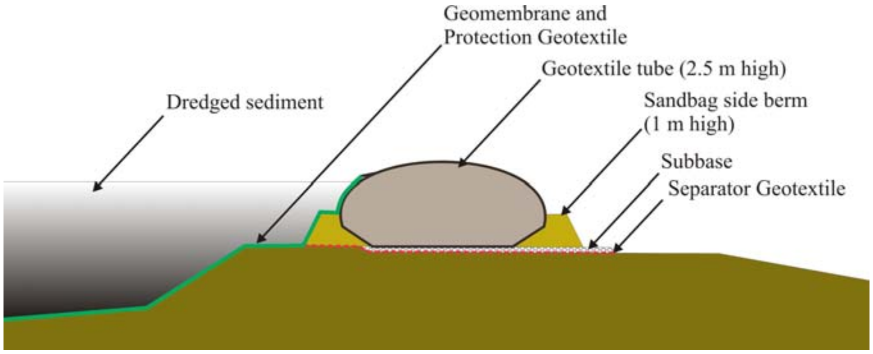


Figure 12. Typical cross section of geotextile tube containment dike.

(a) **(b)**

Figure 13. Geotextile tube dike at Fubaotang (a) subbase and sandbags (b) filling geotextile tube with slurry.

(a) **(b)**

Figure 14. Geotextile tube dike at Liuyuan (a) geotextile tube ready for filling (b) filled geotextile tube.

LAKE REMEDIATION PROJECT, TIANJIN ECO-CITY

Tianjin Eco-City is a new development in China to be undertaken in an ecologically sound and environmentally sustainable manner. The Tianjin Eco-City project is a strategic cooperation between the governments of China and Singapore aiming to improve the living environment and build an eco-culture that will serve as a role model for future developments to come in the country. The site is located on an existing wetland adjacent to the coastline fronting Bohai Bay, about 45 km from Tianjin City centre (see Figure 15). Prior to the development of Tianjin Eco-City, the land consists of generally either natural salt marshes, salt fields and ponds for shrimp and crab farming. The new city will have an area of 31.23 km^2 with a planned population of 350,000. Approximately 70% of the area is derived from the original Hangu District while the balance is from the original Tanggu District. Hangu District

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and Tanggu District together with Dagang District have now been consolidated into the Binhai New Administrative District since November 2009.

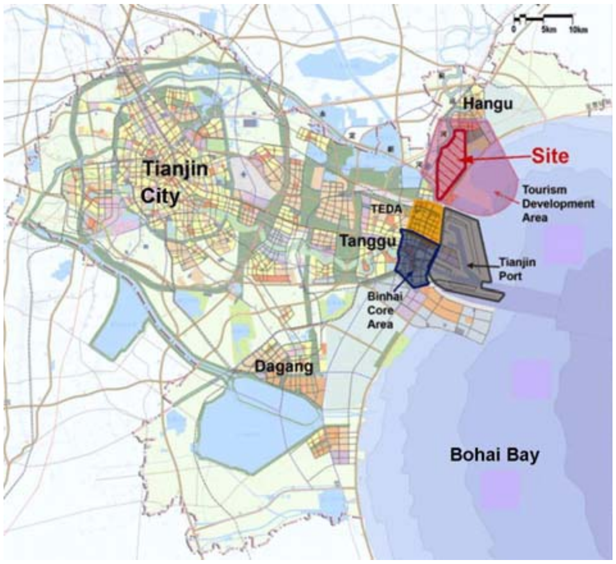

Figure 15. Location of Tianjin Eco-City Development Site.

Hangu Wastewater Lake

In early 1976 the Hangu District Council converted a low lying area to the South by constructing a 3 m high perimeter earth dike to create the Hangu Wastewater Lake. This lake which covers an area of about 3.0 km^2 with an impoundment capacity of 5.6 million m^3 has been receiving wastewater discharges of Hangu District since 1976 thus serving as a giant sludge lagoon. This lake is located within the Eco-City development site (see Figure 16). The lake bottom slopes from the western end to the eastern side of the lake. At the southwestern end of the lake are two pipe sluice gates, each 2 m in diameter. The pipes discharge into a culvert that drains directly to the sea. The Ji Canal flows adjacent to the Hangu Wastewater Lake on its way to the sea. During rainy season when Ji Canal is prone to overflowing the sluice gates are closed to prevent river water backflow into the wastewater impoundment lake.

Figure 16. Location of Hangu Wastewater Lake.

Over the years the wastewater impoundment lake has accumulated 5 million m^3 of contaminated sludge sediments at the bottom of the lake. The thickness of this sludge ranges from 1.3 m to 2.5m with a mean of 1.65 m and average solids content of 10% (Tianjin Eco-City 2009). The top 0.5 m is fairly unstable and can be easily dispersed into the water column when disturbed or carried away by currents. The sludge is contaminated with mercury, arsenic, copper, cadmium, hexachlorobenzene and DDT (Di-chloro Di-phenyl Tri-chloroethane) and the degree of contamination tends to be higher at the wastewater entry point and the acute shores of the wastewater lake (Tianjin Eco-City 2009). Based on current practice adopted in Tianjin for mercury contamination, the contaminated sediments are classified into three levels of contamination i.e. lightly contaminated (mercury concentration of less than 10 mg/kg dry weight), moderately contaminated (mercury concentration greater than or equal to 10 mg/kg dry weight but less than 20 mg/kg dry weight) and heavily contaminated (mercury concentration greater than or equal to 20 mg/kg dry weight). Lightly contaminated sediments account for 38% while moderately contaminated sediments account for 48% and heavily contaminated sediments represent 14% of the total dredging requirement.

Lake Remediation

Integral to the development of Tianjin Eco-City is the plan to remediate the wastewater impoundment lake that is now laden with contaminated sediments. The project to turn the wastewater impoundment area into an ecologically friendly recreational lake and surroundings (see Figure 17) is projected to cost RMB 1.56 billion or about USD 230 million. The sludge is required to be dredged and disposed of or put to beneficial use as part of the lake remediation works. As the sediments to be dredged consist predominantly of fine materials with contaminants and very high water content, they are not suitable fill material in the conventional way for use in land reclamation or other beneficial uses; and disposal at sea is not a viable option. The onshore options considered include beneficial use of solids after dewatering and stabilization or disposal at secured landfill after dewatering.

Figure 17. Artist impression of remediated lake at Tianjin Eco-City development site.

In keeping with its name as Eco-City, the strategy is to maximize the beneficial use of the contaminated dredged sediments in an environmentally permissible way within the Tianjin Eco-City development project. Lightly and moderately contaminated sediments are put to beneficial use while heavily contaminated sediments would end up in a secured landfill. Lightly contaminated sediments are used as road subgrade fill after dewatering and stabilization.

Moderately contaminated sediments are used to construct a lakeside landscaped mound as part of the lake remediation scheme. This solution made a lot of sense. A geotextile tube dewatering facility is first constructed on a reclaimed platform extending from the western side of the lake. The close proximity of the dewatering facility to dredging area minimizes the piping and pumping energy required. The dewatered solids remain secured within the geotextile tubes used for the dewatering process. The proposed dewatering facility being designed along the concept of a landfill with geomembrane underlining and eventual capping means the dewatered solids do not need to be taken to an external landfill. Effluent water from the geotextile tube dewatering process will be returned to the wastewater impoundment lake. A wastewater treatment plant is built to service Tianjin Eco-City in future. This wastewater treatment plant will also be used to clean up the water in the impoundment lake. Earthworks will then proceed on the dried out lake bottom and sides to reshape the lake profile before it is flooded again.

Geotextile Tube Dewatering Evaluations

The effectiveness of a geotextile tube dewatering application is measured by the percentage solids capture, the rate of dewatering and the achievable solids content of dewatered material in the geotextile tube. Effluent water quality is also a measured success criteria, especially when in a proposed application there is no further water treatment prior to the effluent water being released back to the environment. A few test methods are available for evaluating the effectiveness of a proposed geotextile tube dewatering application. Three of such tests were performed in the course of the project planning and design.

Rapid Dewatering Test

The Rapid Dewatering Test (RDT) is used to quickly screen geotextile tube fabric material and chemical accelerant. The slurry and chemical accelerant combination is poured into a container housing the proposed geotextile tube fabric (see Figure 18(a)). Visual observation is made of the solids retention on the geotextile and the clarity of the effluent that has passed through the geotextile (see Figure 18(b)). RDT evaluations were carried out to pre-qualify candidates for subsequent evaluations.

(a) **(b)**

Figure 18. RDT performed at Tianjin Eco-City (a) pouring sample into funnel (b) visual observation of solids retention and clarity of effluent.

Geotextile-tube Dewatering Test

The Geotextile-tube Dewatering Test (GDT) utilizes geotextile tube fabric material formed into a pillow-shape into which is poured the slurry and chemical accelerant combination. The rate of effluent outflow and its quality can be measured. By cutting open the pillow at the end of the test samples can be obtained and tested in the laboratory to determine the final solids content. Based on GDTs conducted the solids content achieved after 30 days was 30%. The effluent quality was very good. Figure 19 shows the GDT conducted at Tianjin Eco-City.

Full Scale Prototype Dewatering Trial

Tests like RDT and GDT are very useful for preliminary assessments but they have their limitations. When a project involves very large quantities of sludge to be dewatered, it is worthwhile conducting a prototype geotextile tube dewatering trial. The trial would allow greater confidence in the design process and provide valuable experience for construction of the large scale project. A total of four suppliers were short listed for the full scale prototype dewatering trial at Tianjin Eco-City.

Figure 20 shows the process sequence of the full scale trial. Geotextile tubes of suppliers, short listed after the RDT and GDT tests, were assessed to compare performance. The geotextile tubes were filled up to a specified control height and then filling was halted to allow the sludge to continue dewatering through the geotextile tube for up to a few days. The geotextile tube height would fall consequentially and another cycle of filling and halting would follow. This sequence of filling and halting was repeated over five to eight cycles, depending on the performance of the individual geotextile tube tested. Final solids content at the end of the trial was determined. This is used for calculating the volume reduction ratio (ratio of insitu volume to final dewatered volume) of the contaminated sediments which would then allow the quantity of geotextile tubes required for the project to be determined.

(a) **(b)**

(c) **(d)**

Figure 19. RDT performed at Tianjin Eco-City (a) mixing of slurry/chemical accelerant (b) pouring sample into GDT set-up (c) comparison of sample and effluent (d) standing above pillow after 13 days.

(a) **(b)**


(c) (d)

Figure 20. Full scale prototype geotextile tube trial performed at Tianjin Eco-City (a) lined drainage platform (b) unrolling of geotextile tube over drainage platform (c) filling geotextile tube with slurry (d) brushing of geotextile tube surface.

Engineering and Design

With initial solids content of 10% increased to final solids content of 50%, the volume reduction will be about 6.1 based on the assumption of 100% solids capture within the geotextile tube. Based on this volume reduction ratio the 2,400,000 m^3 of moderately contaminated lake bottom sediments will reduce to about 390,000 m^3 of dewatered solids remaining in the geotextile tubes. This volume reduction ratio was used to engineer the sizes and stacking of geotextile tubes to form the core of the landscaped mound.

Geotextile Tube Heights

The tube filling control height for the trial was 2.65 m. In an effort to try and fill to rupture, the geotextile tubes were pushed to filled height of 3.3 m. Geotextile tube from one of the suppliers ruptured when filled to a height of 3.0 m, while the others held up well even at filled height of 3.3 m. To optimize the final consolidated height and volume, the filling control height of the geotextile tubes in the final design was benchmarked at 3.0 m. At this height benchmark of 3.0 m, the final consolidated tube height would be expected at 2.3 m. The final geotextile tube dewatering facility is located on a site reclaimed along the western bank of the lake. The dewatering facility was constructed over an area of approximately 120,000 m^2. The length of the dewatering facility was about 760 m while the widest portion was about 230 m. Initially a perimeter dike with crest elevation at EL. +4.0 m is formed to enclose the reclamation area. The enclosed area is then pumped dry to allow ground stabilization works to begin.

Foundation Improvement

To improve the bearing capacity of the foundation for the dewatering facility two layers of high tenacity woven polyester geotextile were used as basal reinforcement. One layer of high tenacity woven polyester geotextile, with ultimate tensile strength of 400 kN/m (in the machine direction), is to be laid at the lake bottom. A sandy gravel layer of 1 m in thickness is then laid above the bottom geotextile layer. This combination of sandy gravel supported with geotextile beneath acted as a stabilization platform to the very soft subgrade and allowed heavy machinery to be deployed for construction works immediately. Another layer of high tenacity woven polyester geotextile, with ultimate tensile strength of 400 kN/m (in the machine direction), is then laid on top of the sandy gravel layer. The minimum desired factor of safety against slip failure through the backfilled mound and the soft foundation underneath is 1.25. The use of two layers of high tenacity woven polyester geotextiles, each with ultimate tensile strength of 400 kN/m, improved the factor of safety to 1.26.

Facility Lining and Drainage

The dewatering facility is designed along the principles of a landfill; consisting of a geomembrane liner for liquid isolation and a drainage system above the geomembrane liner for drainage, collection and removal of effluent water. Compacted earth fill is placed above the top geotextile layer to form the base for the laying of geomembrane liner.

Above the geomembrane liner a nonwoven geotextile cushion layer is laid before drainage aggregate is placed. The top of the dewatering facility platform corresponds to the top of the drainage blanket at EL. +3.65 m. Effluent water from the dewatering process is designed to seep into the drainage blanket quickly. The bottom of the drainage blanket slopes both eastward and westward from a north-south aligned mid ridge at EL. +2.5 m to promote drainage towards the eastern and western edges of the dewatering facility. Two lines of perimeter drains with grilled covers, one on the eastern side and one on the western side of the dewatering facility, are designed to collect the effluent water from the drainage blanket and transfer the water into collection sumps. The base of the perimeter drains corresponds to EL. +2.0 m. The drainage blanket consists of gravels laid to thickness of between 1.15 m (at the ridge) to 1.65 m (at the perimeter drains). Pumps would then be used to remove and return the effluent water to the wastewater impoundment lake. There are two pumping stations on the eastern side and three pumping stations on the western side of the dewatering facility respectively. Figure 21 shows the cross section of the geotextile reinforced sandy gravel foundation platform, compacted earth fill, geomembrane lining system and drainage system above.

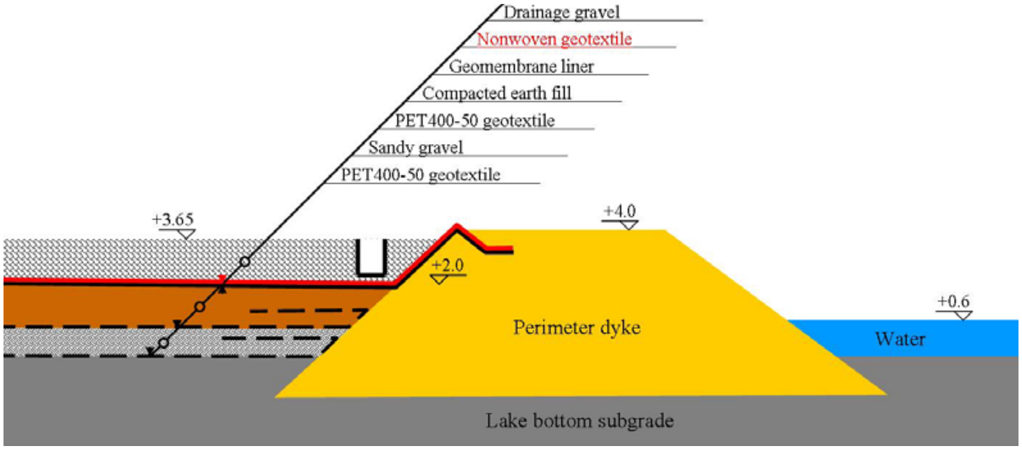

Figure 21. Cross section of reinforced foundation and dewatering platform.

Incoming Slurry Pipelines

Figure 22 shows the incoming slurry delivery pipeline (450 mm diameter) with multiple valve controls and tap off pipes (160 mm diameter). These multiple valve controls are provided at regular intervals along the incoming slurry delivery pipeline to allow convenient branching out to fill the layout of geotextile tubes with slurry. One end of a flexible hose (200 mm diameter) is used to connect to the branching out point while the other end of the flexible hose is connected to a short length of rigid polyethylene pipe (160 mm diameter) which is inserted into the fill port of the of geotextile tube. Chemical accelerant is added to the incoming slurry stream. Sampling points are provided to allow extraction of sample to check quality of treated slurry.

Figure 22. Incoming slurry delivery pipeline and multiple valve control.

Tube Layout and Stacking

Geotextile tubes are detailed for stacking in three layers; each layer to consolidated thickness of approximately 2.3 m. Figure 23 shows the superimposed layout of the three layers of geotextile tubes filled with dewatered sludge. Layer 1 geotextile tubes were standardized using a circumference of 27.5 m. Layer 1 consists of 135 units of geotextile tubes with lengths ranging from 17.0 m to 79.0 m. Layer 2 geotextile tubes were standardized using a circumference of 29.0 m. Layer 2 consists of 86 units of geotextile tubes with lengths ranging from 17.0 m to 79.0 m. Layer 3 geotextile tubes were standardized using a circumference of 30.5 m. Layer 3 consists of 77 units of geotextile tubes with lengths ranging from 13.0 m to 79.0 m. Typically the top surface of a layer of sludge filled geotextile tubes is not flat but would be somewhat wavy. The bottom surface of the upper layer geotextile tubes would form fit into the wavy top surface of the lower layer of geotextile tubes. The use of geotextile tubes with marginally larger circumference for the upper layer is to ensure that a standard layer thickness of 2.3 m is achievable for each layer of consolidated geotextile tubes. The top of the upper layer of geotextile tubes corresponds approximately to EL. +10.55 m.

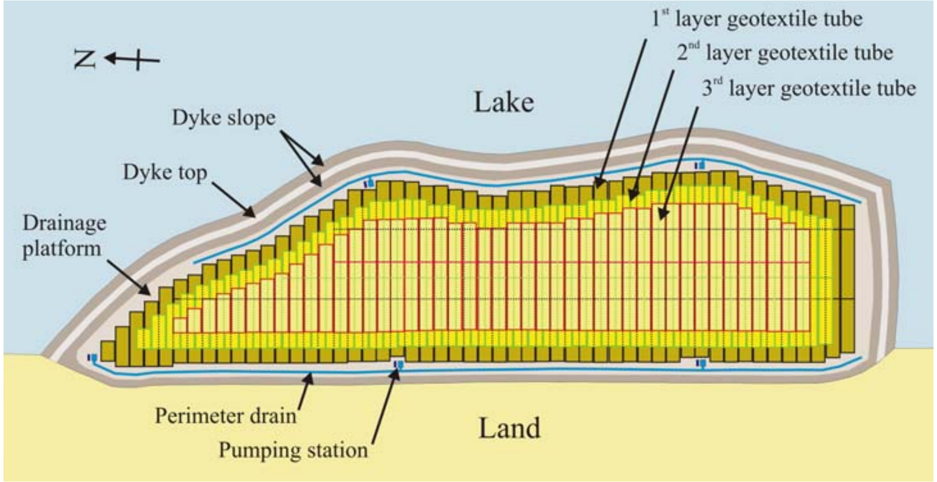

Figure 23. Superimposed layout of the three layers of geotextile tube filled with dewatered sludge.

Final Capping

Figure 24 shows the typical East-West alignment cross section of the artificial mound. Initially, soil is used to cover over the geotextile tubes and form a smooth surfaced mound core. The bermed side slopes are graded to inclination of about 1:5 (vertical:horizontal). The final capping consists of a geomembrane liner laid over the prepared surface and a two layered soil cover placed on top of the geomembrane liner. The lower layer of soil cover consist of 1 m of sandy soil while the upper layer of soil cover consist of 1.5 m of nutrient rich top soil to support vegetation. The finished level of the top of mound averages at EL. +13.05, shaped with a north-south aligned mid ridge that slopes both eastward and westward at a gentle downward inclination of 5% to promote surface runoff.

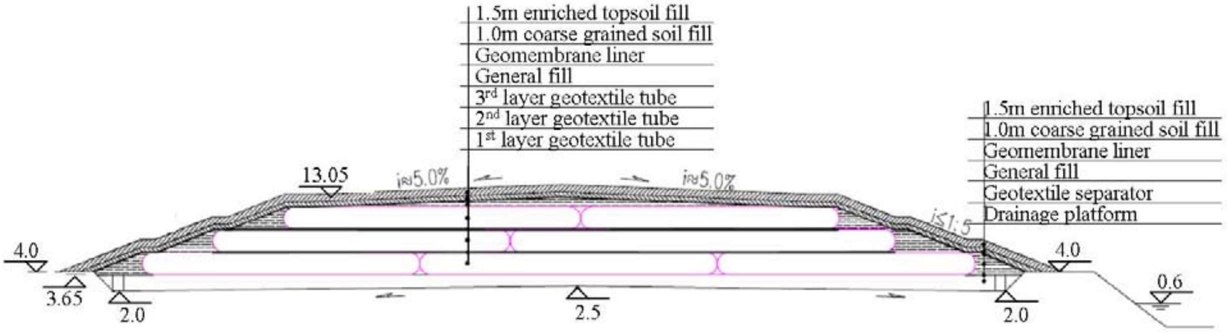

Figure 24. Typical East-West alignment cross section of artificial mound.

Construction

Table 5 shows the project schedule for the wastewater impoundment lake remediation works which included the construction of a lakeside landscaped mound using moderately contaminated lake bottom sediments dewatered with geotextile tube units.

Table 5. Project schedule for lake remediation works.

Item	Work description	Work duration	Starting date	Finishing date
I	Construction of the dewatering facility	151 days	1st Dec 2009	30th Apr 2009
II	Geotextile tube dewatering of moderately contaminated sediments	153 days	1st May 2010	30th Sep 2010
III	Removal of water from lake and treatment	41 days	1st Oct 2010	10th Nov 2010
IV	Excavation to deepen lake; lake side profiling earthworks and landscaping	232 days	11th Nov 2010	30th Jun 2011
IV(a)	Soil cover to geotextile tube and dewatering facility	63 days	1st Dec 2010	1st Feb 2011

Figure 25 shows the backfilling of sand over the bottom layer of high tenacity woven polyester geotextile on 2nd Apr 2010. Construction of the dewatering facility fell behind schedule. This led to a delay in the actual starting of the work involving geotextile tube dewatering of moderately contaminated sediments. The first geotextile tube was laid out and filled on 28th May 2010. In general terms the geotextile tube dewatering work progressed satisfactorily.

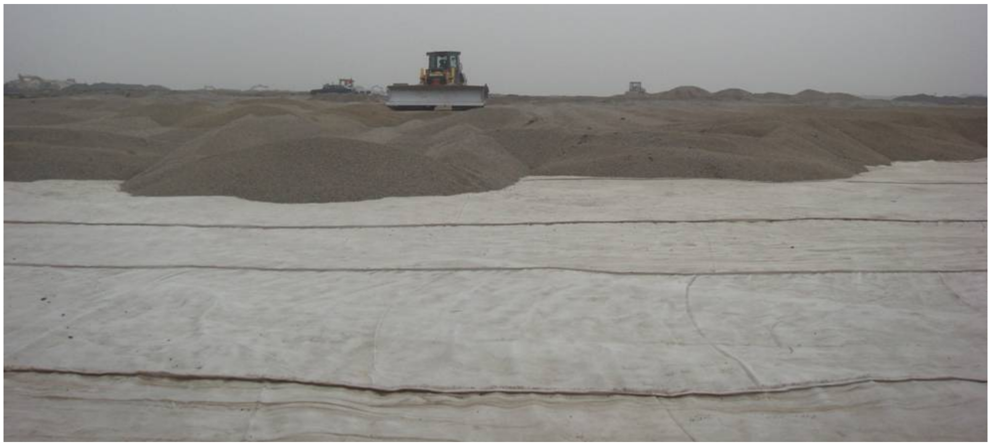

Figure 25. Backfilling of sand over reinforcement geotextile.

In an attempt to catch up on the overall project schedule, the geotextile tube dewatering work was speeded up. This meant each layer of geotextile tubes were allowed less time than required to fill the geotextile tubes with adequate solids. The consequence of that was the design consolidated height of 2.3 m for each layer of geotextile tubes was not achieved. The contract allowed for a 10% variation of quantity for the geotextile tubes. The client decided to utilize this provisional quantity to add a fourth layer of geotextile tubes to achieve the design platform height. Table 6 shows the actual progress of geotextile tube dewatering work at site. Figure 26 shows the overall view of the geotextile tube dewatering work.

Table 6. Actual progress of geotextile tube works at site.

Geotextile tube layer	Circumference	Quantity	Total length	Starting date	Finishing date
1st layer	27.5 m	135 units	7,013 m	28th May	20th Jul
2nd layer	29.0 m	86 units	5,373 m	21st Jul	10th Sep
3rd layer	30.5 m	77 units	3,861 m	11th Sep	10th Oct
4th layer	29.0 m	37 units	2,452 m	11th Oct	30th Oct

Figure 26. Overall view of geotextile dewatering work.

CONCLUSIONS

Three recent case studies in China involving the use of geotextile containers and geotextile tubes to contain and dispose of dredged contaminated sediments has been presented. These projects that cover different applications and conditions provide a snap shot of the current practice of using geotextile containers and geotextile tubes to contain and dispose of dredged contaminated sediments in China.

REFERENCES

Bray, R.N. (2008). *Environmental Aspects of Dredging: Annex A, International Legislation*, Leiden, The Netherlands: Taylor & Francis/Balkema, pp. 301-351.

Cheek, P.M. and Yee, T.W. (2006). "The use of geosynthetic containers for disposal of dredge sediments – a case study" *Proceedings of the Eighth International Conference on Geosynthetics*, Yokohama, Japan, pp. 753-756.

ETWB (2002). "Management of Dredged/Excavated Sediment" *Technical Circular (Works) No.34/2002*, Environment, Transport and Works Bureau (ETWB), Hong Kong.

GB3838-2002 (2002). "Environmental quality standards for surface water" *Chinese National Standard GB3838-2002*, China.

Jin, X.C., Wang, L., and He, L.P. (2006). "Experience and Lessons Learned Brief" *www.worldlakes.org/uploads/11_Lake_Dianchi_27February2006.*

Lawson, C.R. (2006). "Geotextile containment for hydraulic and environmental engineering" *Proceedings of the Eighth International Conference on Geosynthetics*, Yokohama, Japan, pp. 9-48.

Lu, J.J., Yang, H., Gao, L., and Yu, T.Y. (2005). "Spatial variations of P and N in water and sediments of Dianchi Lake, China" *Pedosphere*, 15(1):78-83.

Tianjin Eco-City (2009). "Tianjin Eco-City Wastewater Impoundment Lake Remediation Project" *Technical Specifications of the Tender Document for the Procurement of Geotextile Tubes*. (In Chinese).

Yang, X.E., Wu, X., Hao, H.L., and He, Z.L. (2008). "Mechanisms and assessment of water eutrophication" *Journal of University of Zhejiang SCIENCE B*, 2008(9):197-209.

YIEP (1996). "Yunnan Environmental Project Report, Volume 3" *Addendum to Environmental Assessment Report*, Yunnan Institute of Environmental Protection (YIEP), China.

Yee, T.W., Lim, L.K., and Choi, J.C. (2006). "Geotextile Containment, Dewatering and Disposal of Contaminated Dredged Material" *Proceedings of the International Conference on New Developments in Geoenvironmental and Geotechnical Engineering*, Incheon, Korea, pp. 428-439.

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