A SCENARIO FOR BENEFICIAL USES OF MATERIAL FROM MAINTENANCE DREDGING AT YANGSHAN PORT

Xu Yuan[1]

ABSTRACT

Located in the north of the mouth of the Hangzhou Bay and to the southeast of Shanghai, the Qiqu Archipelago is a large group of islands near to Shanghai, comprising dozens of islands and featuring natural deepwater waterfront. Backing on to the Qiqu Archipelago, Yangshan Port is a typical offshore sea port connected to the mainland by a bridge (East China Sea Bridge). The water body at the port has a characteristically high sediment concentration and high current velocities owing to strong local tides and being adjacent to the Changjiang Estuary which is abundant in incoming water and sediment. Thus, it can be expected that there will be several million cubic metres of material from maintenance dredging at the port requiring to be used beneficially or disposed of every year after the Port comes into service. This paper discusses in detail the possible beneficial uses of the material from maintenance dredging at Yangshan Port in the following aspects: appropriate maintenance dredging methods, environmental requirements for material treatment and suitability of locations within the port for material treatment. Consideration was given to the plan form of the port, sites where the maintenance dredging will be carried out, soil strength and the requirements for sustainable development.

Key Words: Yangshan Port, Maintenance Dredging, Material Treatment, Land Reclamation.

INTRODUCTION

At present the port and harbor construction in China is developing rapidly at an unprecedented pace, and the future ten years or even a longer period will witness a peak time for the construction and extension of coastal ports, harbors and navigable channels. Accordingly, large quantities of sand will need to be dredged from harbor basins and channels, and large areas of land will need reclaiming. According to incomplete statistics, it is predicted that the total amount of capital dredging at major ports and harbors along the coast of China from 2006 to 2010 will reach up to 600 million m^3 and the annual amount of maintenance dredging will be more than 50 million m^3 (Zhu Zhi et al, 2006). But the current situation facing dredging works and land reclamation works is that on one hand, more than 60% of dredged material is disposed of at sea or in river but on the other hand, many land reclamation works have to use quarry stone due to a lack of sandfill material suitable for land reclamation. How to balance economic development and resource utilization with environmental protection is an important issue to which much attention must be paid in the new round of development and construction of harbors, ports and navigable channels in China.

Dredged materials can be pumped into a mud storage area and then by taking the necessary steps an area of land will be reclaimed. This is the common practice in relation to the beneficial use of dredged materials both at home and abroad. However, most of these projects are relatively small in terms of volume of material to be dredged, annual volume of dredged materials pumped and the size of mud storage areas, when compared with Yangshan,, The proposed material treatment works at Yangshan Port will require the pumping of 14.00~18.00 million m^3 of dredged material a year. It is the first project of this size in China and, indeed, also a rare event in the world.

BASIC PHYSICAL CONDITIONS AND DISTRIBUTION OF MATERIALS TO BE DREDGED AFTER COMMISSIONING

Location and Dynamic Conditions of Water and Sediment

Located in the north of the mouth of the Hangzhou Bay and adjacent to the Changjiang Estuary which features an abundance of incoming water and sediment, the Yangshan Sea Area is named after Da Yangshan and Xiao Yangshan, the two biggest islands of the Qiqu Archipelago. The archipelago is composed of two chains of islands: the north and south chains that flare westward (towards the inside of the Hangzhou Bay) in a plane shape. The south chain comprises Tangnaoshan, Shuanglianshan, Dashantang, Da Yangshan and other islands while the north chain includes Da Wugui, Kezhushan, Xiao Yangshan, Ximentang and Zhongmentang. Because of the actions of currents and the natural effects of the islands, a vast tract of water with a depth greater than 12m is formed around the

[1] Chief Engineer, Shanghai Waterway Engineering Design & Consulting Co. Ltd, 850 Pudong Avenue, Shanghai 200120, China, T: 86-21-58785717, F: 86-21-58788265, E-mail:xuyuan@shiw.com.cn

archipelago. What's more, between the two chains of island there exists an even deeper water area with depths greater than 15m. This area is also wide and enjoys good conditions for providing shelter.

The Yangshan Sea Area is influenced by the East China Sea progressive tidal waves, and belongs to a zone with a medium tidal range. The tides are characterized by alternating current, flowing in a ESE-WNW direction in open waters. Near the islands, the current direction tends, due to local topographic effects, to be linked to the underwater slope of the islands and reefs. The current velocity in this latter area is greater in strength than that in open waters due to narrow passage and effect of the islands. The max velocity is 2.0~3.0m/s during spring tides and 1.0~1.5m/s during neaps (Xu Yuan, 2001).

The ocean current that has an effect on this sea area is the Taiwan Warm Current and shore currents are the Yellow Sea and East China Sea Coastal Currents (Xu Yuan, 2001). Owing to seasonal changes in the above ocean and shore currents, and being adjacent to the Changjiang Estuary that has abundant in incoming water flows and sediment, the water body of this marine area features high sediment content in winters (up to 1.5~2.5kg/m^3) and low sediment content in summers (0.3~1.0kg/m^3). Moreover, fine-particle sediment is not liable to settle between the islands and reefs due to the larger velocities there. High sediment content in the water body around the islands and reefs is one of the major characteristics of the Yangshan Sea Area. This is the reason why the port after commissioning will have to face a large amount of maintenance dredging.

The sea area belongs to the mid latitude East Asian monsoon zone. Strong winds and rough seas usually occur during typhoon periods that generally last from July to September and during cold front periods that usually last from December to February. These usually have significant effects on the local current and sediment fields.

Port Construction Planning and Functional Layout

The construction of Yangshan Deepwater Port depends upon the north and south chains of islands of Qiqu Archipelago. For the initial phases, the North Harbor District will be constructed along the north chain (Figure 1), comprising Xiao Yangshan Harbor District (Phase I and II), Xiao Yangshan Middle Harbor District, Xiao Yangshan West Harbor District and Xiao Yangshan East Harbor District. Sometime in the future, the South Harbor District will be constructed upon the south chain, to eventually form the whole harbor district flaring towards the inside of the Hangzhou Bay (CCCC Third Harbor Consultants Co., Ltd., 1998).

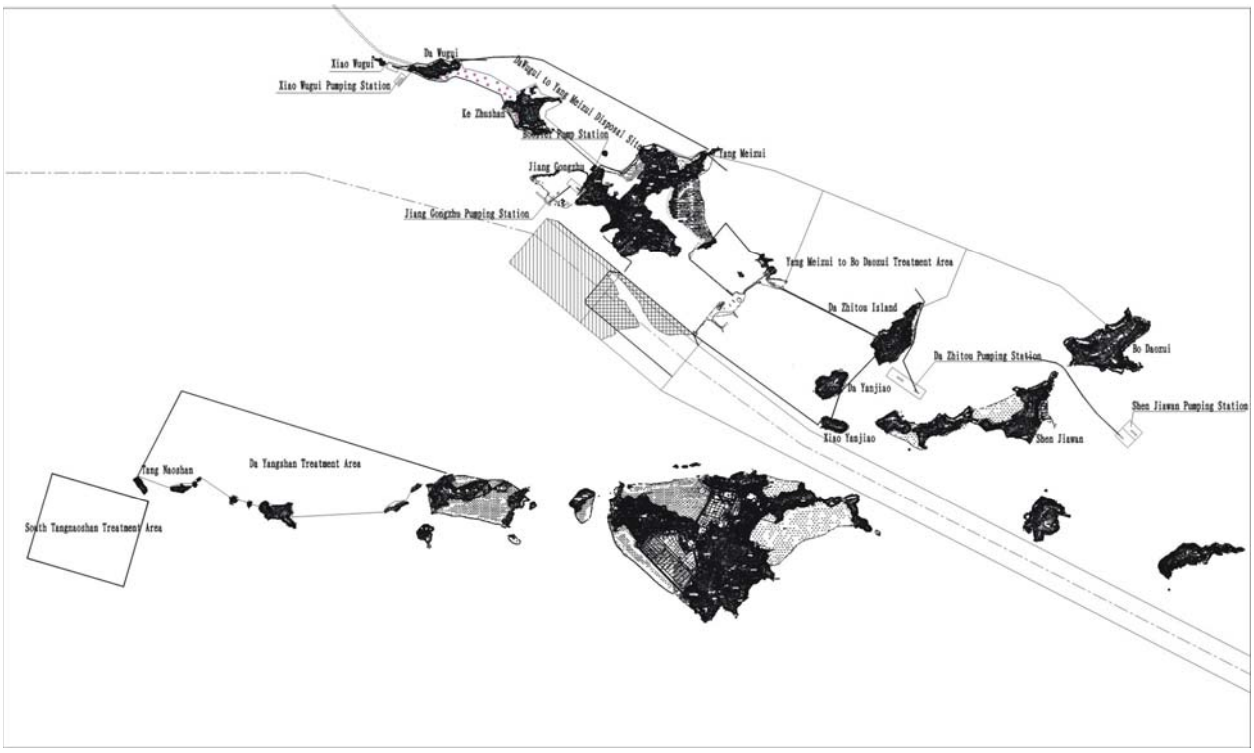

Figure 1. General layout of Yangshan deepwater port and the material treatment areas.

The Xiao Yangshan Harbor District (Phase I and II), which has been completed and been commissioned, is a stevedoring district for containers running ocean routes. Its wharf frontage is 3km long. The Xiao Yangshan Middle Harbor District, close to the east side of the Xiao Yangshan Harbor District (Phase I), is also a stevedoring district for containers running offshore and coastal routes. Its planned waterfront consists of a wharf 2.6km long. At present, the land reclamation work has been completed. The Xiao Yangshan West Harbor District, close to the west side of the Xiao Yangshan Harbor District (Phase II), is a stevedoring district for containers running offshore and coastal routes. Its planned waterfront wharf is 3.85km long. The Xiao Yangshan East Harbor District, located at the east side of the Xiao Yangshan Middle Harbor District, is a stevedoring district for energy resource handling and its planned waterfront is a wharf 3.5km long.

The whole harbor area is divided into cargo handling and services areas and processing areas. At present, the cargo handling area in the North Harbor District has basically taken shape, and the construction of its services and processing area has already been put on the agenda. Taking into account the functions required and local conditions, it is better to locate related services to the north of the cargo handling area, i.e. along the line from Yangmeizui to Bodaozui near to the Islands (Shanghai Waterway Engineering Design and Consulting Co., Ltd., 2005).

Distribution of Materials to Be Dredged and Planned Material Treatment Sites

Demands for Dredging

In accordance with the general planning of the port, the distribution of material to be dredged at Yangshan Port has a distinct regional characteristic. The materials to be dredged are mostly concentrated in two areas: one is inside the waters of Phase I, Phase II and West Harbor District (berths and turning basins) and the other is in the artificial dredge-cut along the Access Channel. The two areas are more than 10km away from each other. The volumes of capital dredging and maintenance dredging will vary greatly in different stages of development of the port, but definitely the annual volumes of treatment of dredged material will be huge (See Table 1).

Table 1. Annual demands for dredged material treatment in different areas.

Area	Areas to be Dredged in Different Stages	Annual Demand for Material Treatment	Remarks
Waters inside the Port	Phase I and II maintenance dredging	5 million m^3	2007~2009
	Phase I and II maintenance + capital dredging at West Harbor District	11.50 million m^3	Capital dredging of the harbor basin in the West Harbor District in 2010, duration: 1 year
	Phase I and II maintenance + maintenance dredging at West Harbor District	7.50 million m^3	From 2011
Artificial Dredge-cut Along the Access Channel	One-way channel maintenance + capital dredging to widen the channels	18.00 million m^3	To be executed in 2007, duration: 1 year
	Two-way channel maintenance dredging	6.50 million m^3	From 2008

The calculation for dredging based on the planned dimensions and general layout of the port shows that the volume of capital dredging at the West Harbor District will be around 6.50 million $m^{3.}$ The artificial dredge-cut section along the Access Channel which will be widened from 300m-wide one-way channel to 550m two-way channel will involve the dredging of around 14.00 million m^3. Based on related studies and measured data, it is predicted that the annual maintenance dredging volume in the Phase-I and Phase II harbor districts when completed will be about 5.00 million m^3, that in the West Harbor District about 2.50 million $m^{3.}$ This results in a total of about 7.50 million m^3 of material to be dredged within port waters. The annual volume of maintenance dredging at the artificial dredge-cut section of the Access Channel, which is a one-way channel now, is predicted to be 3.60 million m^3. In the future, the channel will be widened to a two-way channel. The annual volume of maintenance dredging will then be 6.50 million m^3. It can be seen that the maximum demand for material treatment at the harbor basins is 11.50 million m^3, and the regular demand in the North Harbor District after commissioning will be 7.50 million m^3. The maximum demand for material treatment from the Access Channel is 18.00 million m^3, and the regular demand after being widened will be about 6.50 million m^3.

SITING OF DREDGED MATERIAL TREATMENT AREAS

Yangmeizui to Bodaozui Treatment Area

With (1) the byway from Xiao Yangshan to Huogaitang blocked by the north dike in the east of Phase-I Project, (2) the byway from Jiangjunmao Island to Da Zhitou Island blocked by the north dike in the east of the Middle Harbor District and (3) the byway from Da Zhitou Island to Middle Ximentang Island blocked by the dike connecting to the LNG terminal, the tidal currents in the area from Yangmeizui to Bodaozui to the north of these dikes decreases rapidly and the area becomes an area of deposition. This area will be impounded and reclaimed and a comprehensive services center will be built there as planned. The impounded area will have an area of 12.7km^2 or so and has an average water depth of 6.2m at present. Considering a 5.5m temporary reclamation level and 3m of silting by accelerated siltation, then the volume of sandfill required for reclamation is estimated to be up to 110 million m^3. The Treatment Area is located to the north of the harbor basins. Since the Kezhushan Bridge is not navigable, if mud barges are used, they will have to detour round Middle Ximentang Island ~ Bodaozui and the dumping distance will be above 22km. A reasonable method is to use large trailing suction hopper dredgers to load, sail to a material treatment area and dump. But most parts of this area are not deep enough for large hopper trailers to navigate (vessels could only sail in at high water). Therefore, pipelines will be laid on a reasonable route leading to the material treatment area.

Da Wugui to Yangmeizui Treatment Area

Based on a preliminary proposal for the construction of the West Harbor District, the byway from Kezhushan to Xiao Yangshan will be blocked off. The waters to the north of this area enjoy favorable conditions for reclamation. The area of these waters is about 2.6 km^2, the average depth at present is about 12.3 m. It is estimated that after the byway is blocked off and dikes that have the aim at accelerating siltation are completed, silting will be to a depth of 6m. Therefore, this area will have the capacity to hold around 31.00 million m^3 of sandfill. Pipelines will also need to be laid to this treatment area through which material dredged in the harbor basins can be pumped.

Da Yangshan Treatment Area

In accordance with the general planning of Yangshan Port, the South Harbor District (the south chain of islands around Da Yangshan) will be constructed after the completion of the North Harbor District (the north chain of islands around Xiao Yangshan). Large quantities of fill material will be needed to reclaim areas of land for the construction of the South Harbor District. A preliminary study shows that blocking the bypasses between islands in the south chain and building dikes with the aim of accelerating silting on the north side will accelerate silting here and greatly reduce the demand for fill material for future reclamation. Moreover, the blocking of tidal passages will make currents more concentrated, which is good for reducing the amount of silting inside the harbor basins. The areas enclosed by blocked byways between the islands and dikes on the north have an opening that can be used as a dumping site for the disposal of dredged material. Taking, as an example, the impounded area formed by blocking the byway from Shuanglianshan to Tangnaoshan and building a dike on the north, the water area is about 5.8km^2, average depth is 13.8m and silting is estimated to be 4m. The area will then need 72.00 million m^3 or so of fill material to complete the reclamation.

DREDGING METHODS

There are several methods that can be used in connection with different dredging quantities, soils and working conditions, but trailing suction hopper dredgers and cutter suction dredgers will be the primary equipment to perform the dredging work. Depending upon the characteristics of Yangshan Port and the experience from Phase-I dredging, these methods are suitable for the following capital and maintenance dredging and material treatment: dumping-pumping, dredge-transport-pumping, dredge-pumping, and dumping. For the first three methods, “dredging” will basically be performed by large trailing suction hopper dredgers while “pumping” will be mainly performed by cutter suction dredgers. Fixed suction and pumping equipment may be used as a substitute under favorable working conditions (which will not be discussed here for simplification). The dumping method is the simplest but the most efficient of all the methods. However, there is now a developing emphasis on environmental protection which has resulted in a change in approach whereby dredged material is regarded as a resource rather than a waste. This is especially important in an area like the Yangshan Port which is short of sand and stone but badly in need of fill material for reclamation. Therefore, the dumping method can only be used when a huge-quantity of silting occurs in a large-area in a short period of time. This may be having an influence on the operations of the port or be before the completion of an impounded area for material treatment during the capital construction periods. Either way the situation should be monitored closely.

Dumping-Pumping Method

A trailing suction hopper dredger will transport dredged material to a pumping station after dredging and loading in harbor basins or channels, and dump dredged material into a re handling pit. Then the material will be pumped with a specialized reclamation dredger or equipment at this pumping station. Generally a pumping station has two dredged material re handling pits. When a trailing suction hopper dredger is dumping into one pit the reclamation dredger will pump sand out of the other pit. After one pit is full, the reclamation dredger will move in to pump out and the trailing suction hopper dredgers will dump in the other.

The dumping and pumping method gives full play to the respective capabilities of a hopper dredger and a reclamation dredger and equipment and ensures both dredging operations and pumping operations have a high efficiency. However, this method has two separate operations: dumping and then pumping rather than the single dredge-pumping method. This will inevitably result in some loss of dredged material. The method of connecting the reclamation dredger to the terminal is subject to a requirement for the reclamation dredger to be able to move about in the pit. Therefore floating pipelines will be used. The suitability of this method is subject to the working conditions for floating pipelines and the use of suitable pipelines. The production rate for this method is subject to the reclamation dredger and equipment chosen with the discharge distance subject to the power of dredge pump installed at the pumping station.

Dredge-Transport-Pumping Method

A trailing suction hopper dredger will tow 2 mud barges (mostly self-propelled) on both sides while dredging in a harbor basin or channel and transfer dredged material to the mud barges. In the case of dredging at berths, a grab dredger will dredge soil and discharge into the mud barges. The dredged material will then be transported on the mud barges to a pumping station (platform), and then pumped using a reclamation dredger or equipment through discharge pipelines to the treatment areas. This method uses mud barges to transport dredged material from the dredging site to a pumping station, which will greatly lower the requirement for water depth when locating a pumping station. Moreover, the method is relatively simple, no dumping in a pit, no pumping from a pit. However, the barges will frequently shuttle between the basin or channel and the pumping station and will have an influence on the commercial shipping movements in the port. On the other hand, it is not easy for a barge to berth alongside or leave a trailing suction hopper dredger and this will have some effect on the dredging efficiency of a hopper dredger. Also the dredgers and barges are not very seaworthy and this method can only be used with a maximum allowable wind speed of about scale 6.

Dredge-Pumping Method

The dredge-pumping method means a trailing suction hopper dredger will directly pump the dredged material to the disposal site so as to avoid any loss of material during dumping and the need for re dredging from a re handling pit. If the hopper dredger is equipped with a bow pumping installation an additional berthing facility is not necessary. At present, there are only a few large hopper dredgers that are furnished with this pumping function in China and their discharge distance is limited. In addition, the disadvantage of the dredge-pumping operation is that it greatly lowers the dredging efficiency of a hopper dredger and has a higher requirement for water depth because of the larger drafts.

Dumping Method

The dumping method means that a hopper dredger directly sails to a designated dumping site for dumping after dredging. This method, subject to there being no influence on the environment around the dumping site, features simple processes, is easy to operate, economical within certain limits for dumping distances, and suitable to a wide variety of working conditions. Calculations based on Soil Scale 2 and Working Conditions Scale 5 show that a 4500m^3 trailing suction hopper dredger will yield a production of 3.90 million m^3 and 1.90 million m^3 a year at 10km and 28km dumping distances respectively.

DREDGED MATERIAL DISPOSAL OPTIONS

Waters Inside the Port

Jianggongzhu Pumping Station and Yangmeizui-Bodaozui Treatment Area

Adopting the dumping-pumping method plus the dredge-pumping method a pumping station will be located in a temporary sheltered basin to the north of Jianggongzhu Island. Inside the pumping station, there will be material re handling pits and a cutter suction dredger will pump the material into the Yangmeizui to Bodaozui Treatment Area.

The entrance of the shelter basin is only 70m wide, and the space inside the basin is only big enough for barges to sail into and dump.

The berths will be dredged with a grab dredger and the dredged material will be transported on barges to the material re handling pits for dumping. The waters where the workboat berth lies enjoys a strong current and therefore not suitable for the dumping-pumping method. The workboat berth will be kept in existence until the construction of the West Harbor District and can be used as a pumping platform for materials from maintenance dredging at the turning basin. A trailing suction hopper dredger, after dredging and loading, will take up the berth pocket, pump the dredged material mixture into its hoppers then dump into the re handling pits in the temporary shelter basin.

Based on the estimation of annual quantities of materials from maintenance dredging in the waters inside the port, the pumping station should have a capacity of 5.00 million m^3 a year and be furnished with one 1450m^3 cutter suction dredger together with 3.5km-long discharge pipelines leading to the disposal site via the west foot of Xiao Yangshan. The turning basin should be dredged with two 4500m^3 trailing suction hopper dredgers, together with 0.8km-long discharge pipelines for pumping starting from the workboat berth to the material re handling pit via the land area behind it. The berths should be dredged with one 4~13m^3 grab dredger, supported by one 1000m^3 barge and a tugboat. The dumping distance is about 3km.

This pumping station is a temporary one and will be used for any maintenance dredging inside the port before the construction of the West Harbor District.

Xiao Wugui Pumping Station and Da Wugui to Yangmeizui or Yangmeizui to Bodaozui Disposal Site

The byway between Kezhushan and Xiao Yangshan will be blocked off and the ianggongzhu Pumping Station will then be removed with the construction of the West Harbor District as per the layout of the West Harbor District. As a substitute, the Xiao Wugui Pumping Station, which will be in use for a long time, will be located in the west of the West Harbor District. Since the currents are strong and it is not feasible to set up an open re handling pit there for dumping operations, it is proposed to arrange a basin to be dug out that will to be used for dumping and pumping operations. The berths will be dredged with grab dredgers and the dredged materials will be transported on mud barges to the re handling pit for dumping. The turning basins will be dredged by using a large trailing suction hopper dredger which, after loaded, will sail to and dump in temporary re handling pits where a cutter suction dredger will pump the mixture to the disposal site. There are two options for a disposal site, one is Da Wugui to Yangmeizui Treatment Area, and the other is Yangmeizui to Bodaozui Treatment Area. The latter needs an additional booster pump station to be installed on the land area.

Based on the estimation of annual quantities of material from maintenance dredging in the waters inside the port, the pumping station should have a capacity of 7.50 million m^3 a year and the dumping distance of a large hopper dredger or mud barge will be about 4km. The pumping station should be furnished with one 1600m^3 cutter suction dredger together with a 2km or 8km long discharge pipelines leading to the disposal sites. The turning basin should be dredged with two 4500m^3 trailing suction hopper dredgers. The berths should be dredged with one 4~13m^3 grab dredger, supported by one 1000m^3 mud barge and a tugboat.

Da Zhitou Pumping Station and Yangmeizui to Bodaozui Treatment Area

A shelter basin for small boats will be built in the waters between Xiao Yanjiao ~ Da Yanjiao and LNG tank farm and its connecting dike on the north. It is an appropriate site for a pumping station where a dumping-pumping method will be adopted. The pumping station will be 8km away from the area to be dredged inside the port and the discharge pipelines will be placed around the east foot of the Da Yanjiao to the Yangmeizui~Bodaozui treatment area. The pipelines will be about 2km long, which meets the economic requirements for dredged material treatment.

The annual capacity of the pumping station and type of dredger and equipment chosen are identical to those at the Da Wugui Pumping Station. This one is an alternative to the Da Wugui Pumping Station.

Da Yangshan Treatment Area

Materials dredged with large trailing suction hopper dredgers or grab dredgers (together with mud barges) in the waters inside the port will be transported and dumped into the planned land Treatment Area for the construction of the Da Yangshan Harbor District. The dumping distance is about 7km. This method of operation is similar to conventional dumping in terms of efficiency. The difference here is that the dredged material is dumped into an impounded area which has an entrance to allow large trailing suction hopper dredgers to sail in and out. Calculated

on the basis of using two 4500m^3 trailing suction hopper dredgers to dredge in the turning basins and one 4~13m^3 grab dredger, together with one 1000m^3 mud barge and a tugboat, to dredge in the berths, about 8.00 million m^3 of dredged materials will be dumped into this Treatment Area each year.

South Tangnaoshan Treatment Area

Materials dredged in the waters inside the port are dumped at a disposal site outside the Phase I Harbor District. The dumping distance is 28km and the cost of dumping is rather high. Moreover, the dredgers and barges have to frequently cross the N-S channel, which causes a disturbance to normal commercial shipping. So a new disposal site inside the port and to the south of Da Yangshan chain of islands is proposed to be located to the south of the chain of islands from Tangnaoshan to Shuanglianshan to Da Yangshan, about 10km away from the dredging site inside the port. The disposal site is 2.5km^2 in area, the projected dumping depth is 3m and it will hold 5.00million m^3 of fill material. Judging by a relevant mathematical current field model computation, currents in this sea area have bigger velocity and likely to cause diffusion of material. However, the sediment diffusion will not have any significant influence on the waters inside the port because the prevailing wind direction is East-West.

Access Channel

Shenjiawan Pumping Station and Yangmeizui to Bodaozui Treatment Area

The dredged materials will be disposed of by the dumping-pumping method. Shenjiawan Pumping Station will be set up, i.e. a sediment pit will be located on the shoal to the east of Shenjiawan Island where currents are relatively weak, and a large cutter suction dredger will pump the mixture through submerged pipes to the Yangmeizui ~ Bodaozui Treatment Area.

The annual maintenance dredging volume at the Access Channel will be 3.60 million m^3 in the short term and 6.50million m^3 in the long term. This work can be carried out separately with one or two 4500m^3 trailing suction hopper dredgers with about a 13km dumping distance together with one 1000m^3 or 1600m^3 cutter suction dredger with 2km pipelines.

Xugongdao Dumping Site

The dumping site for the Phase I project is located between Bitoujiao and Shangchuanshan Island to the north of the Access Channel. The area of the dumping site is 5km^2 and its distance to the dredging site at the Outer Channel is about 10km. Judging by the bathymetric survey, the depth at the dumping site will not change greatly in a year after dumping, and can still accept the amount of dredged material.

Determination of Dredged Material Disposal Options

It can be seen from the above analyses that there are four options for the siting of pumping stations inside Yangshan Port (Sea Table 2). Among others, the Jianggongzhu Pumping Station can only be used as a temporary pumping station due to the uncertainty in the construction of the West Harbor District. The Xiao Wugui Pumping Station will have to occupy about 400m waterfront, which seems to be a serious disadvantage to this option in the context of Yangshan Port where the waterfront resources are rare. Although Da Yangshan Dumping Site may be a preparation for the construction of the South Harbor District ahead of time, the construction of the services area in the North Harbor District will obviously precede the South Harbor District. On the other hand, the South Harbor District is still at a design stage, and it is impossible to perform the impounded work in the near future. Therefore, Da Zhitou Pumping Station will be the only option for dredged material disposal within the port for the time being. Judging from the maximum disposal demand and normal demands in the port, it is proposed that the pumping station should have the capacity of pumping 7.50 million m^3 of dredged material a year and the amount exceeding the capacity of this station during the capital dredging at the West Harbor District should be disposed of elsewhere.

Table 2. Table of comparison between different material disposal options.

Area	Waters inside the Port					Artificial Dredge-cut at the Access Channel
Pumping Station	Jianggongzhu Pumping Station	Xiao Wugui Pumping Station		Da Zhitou Pumping Station	The Dumping Option	Shenjiawan Pumping Station
		Alternate I	Alternate II			
Treatment Area	Yangmeizui ~ Bodaozui	Da Wugui ~ Yangmeizui	Yangmeizui ~ Bodaozui	Yangmeizui ~Bodaozui	Da Yangshan Dumping Site	Yangmeizui ~ Bodaozui
External Conditions	Before the byways between Kezhushan and Xiao Yangshan blocked up, part of waterfront of workboat wharf and the shelter basin for small boats are temporarily used, and dikes are to be built for reclamation.	After the West Harbor District is completed, a certain part of the waterfront of wharf should be kept for setting up the pumping station and dig-in basin, and dikes should be built for reclamation.		The shelter basin for small boats will be used, reef blasting is necessary at the east of Xiaoyanjiao, dikes should be built for reclamation.	Dikes should be built to form a Treatment Area. The layout of dikes in this area is complex, demonstration by mathematic model and physical model is necessary after execution.	Dig the mixture pit on the shoal to the east of Shenjiawan, corresponding navigable channel for dumping should be dredged. Dikes should be built for reclamation.
Construction Method	Dredge-pumping + dumping-pumping	Dumping-pumping	Dumping-pumping + booster pump station	Dumping-pumping	Dumping	Dumping-pumping
Annual Pumping Capacity	5.00M m^3	7.50M m^3	7.50M m^3	7.50M m^3	7.50M m^3	6.50M m^3
Dredgers and Equipment	2×4500m^3 hopper dredge 1×1450m^3/h cutter suction dredge	1×4500m^3 hopper dredge 1×1600m^3/h cutter suction dredge	1×4500m^3 hopper dredge 1×1600m^3/h cutter suction dredge 1×booster pump station	2×4500m^3 hopper dredge 1×1600m^3/h cutter suction dredge	2×4500m^3 hopper dredge	2×4500m^3 hopper dredge 1×1600m^3/h cutter suction dredge
Estimated Unit Rate per m^3 (RMB)	18.3	13.9	16.1	19.9	9.7	23.0
Capital Cost for Pumping Station Set-up (million RMB)	pipeline: 16.00	Pipeline:9.00	Pipeline:30.00 Booster Pump Station: 20.00	Pipeline:12.00	——	Pipeline:12.00

Shenjiawan Pumping Station is the only choice for the beneficial use of materials dredged at the artificial dredge-cut of the Access Channel. Judging from its maximum and normal pumping demand, the pumping station should have the capacity of pumping 6.50 million m^3 of dredged material a year and the part of dredged materials exceeding its capacity due to channel widening should be disposed of at a dumping ground.

CONCLUSIONS

1. In the North Harbor District of Yangshan Port, the cargo handling area has already taken shape, so the construction of its services and processing areas, especially the land reclamation works must be performed under such circumstances. A reasonable site for the services and processing areas is in the waters near the islands from Yangmeizui to Bodaozui to the north of the cargo handling area.

2. In Yangshan Port, the distribution of dredged materials has a remarkable regional characteristic. Material that is to be dredged is mostly distributed in the waters inside the port (harbor basins and turning basins) and in the artificial dredge-cut of the Access Channel. In the waters inside the port, there will be at the most 11.50 million m^3 of dredged material available for reclamation, and the normal amount of dredged materials for reclamation after the North Harbor District is put into operation will be 7.50 million m^3. In the Access Channel, there will be at the most 18.00 million m^3 of dredged material available for reclamation, and the normal amount of dredged material for reclamation after the channel being widened will be 6.50 million m^3.

3. The construction methods that are suitable for the capital and maintenance dredging and beneficial uses or disposal of dredged materials in Yangshan Port include dumping-pumping, dredge-transport-pumping, dredge-pumping and disposal at a dumping site. In accordance with the general layout of the port and features of the local waters, the following dredged material use or disposal sites are proposed: Da Wugui to Yangmeizui, Yangmeizui to Bodaozui, Da Yangshan Treatment Area, South Tangnaoshan Dumping Site and the Xugongdao Dumping Site.

4. Setting up the Da Zhitou and Shenjiawan Pumping Stations is the only choice for the disposal of material dredged from inside the port and the Access Channel. The former should have a capacity for pumping of 7.50million m^3 of dredged materials a year, and the latter 6.50 million m^3 of dredged materials a year. The volume exceeding their capacities during the capital dredging periods will be disposed of at a dumping site. This disposal site is at the Yangmeizui to Bodaozui Treatment Area.

REFERENCES

The Third Harbour Engineering Design & Consulting Co. Ltd (1998). *General Plan of Yangshan Port.*

Shanghai Waterway Engineering Design & Consulting Co. Ltd (2004).*The Preliminary Study for Dike Engineering of .Xiaoyangshan Services and Processing Area.*

Xu Yuan (2001). "Rationale for Dredging Frequncy Using Hydrologic and Sediment Characteristics ----Yangshan Sea Area." *Congress Proceedings of the 16th World Dredging Congress*, Kuala Lumpur, Malaysia .

Zhu Zhi, Xu Yuan (2006). "Study and Practice of Comprehensive Utilization of Dredging Soil of the Deep-water Channel Engineering in Changjiang Estuary ". *Proceedings 2nd Chinese International Dredging Technical Development Congress and Exhibition* , Guangzhou, China.