

LAND RECLAMATION IN SOUTHEAST ASIA

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ABSTRACT: Reclamation is a widely accepted method for obtaining land in Southeast Asia. For placement method, hydraulic filling using marine source is commonly used. Suction dredgers are widely used to win marine sand for reclamation projects. With well planing and designs, these dredging vessels can supply millions cubic meters of fill in a clean and effective manner. The custom built suction dredgers used for the reclamation project in Mailiao, Taiwan are excellent examples and is discussed in details. Densification is generally required to improve the strength of hydraulic fill and reduce its settlement. Many densification methods applied in reclamation projects in the Southeast Asia region are also introduced.

INTRODUCTION

Countries in East Asia have been reclaiming land from the sea as a solution for satisfying the ever-increasing demand for land since the 19th century. The reconstruction after 1945 and the economical growth since then required extensive civil engineering infrastructure on reclamation areas. Reclaimed lands have been widely used for harbors, wharves, airports, power plants, industrial and commercial developments, and so on. Due to the rapid growth in recent years, more and more vast scale reclamation projects have been carried out in this region.

Dredging is a very cost-effective method in placing marine sand source to the designated area. The plain suction dredgers are valued tools not only for inshore sand reclamation but also offshore sand reclamation. Also, the selection of dredgers is directly related to their capability to operate under the prevailing sea conditions. This paper concentrated on the discussion of a successful land reclamation project using the custom built plain suction dredgers at Mailiao, Taiwan. In addition, the land reclamation works in the Southeast Asian region was briefly introduced. The improvement techniques commonly used on land reclamation projects were also given.

LAND RECLAMATION IN SOUTHEAST ASIA

Reclamation in Southeast Asia can be dated back to the mid-nineteen century. Shortly after 1841 minor reclamation took place along the shoreline of the Hong Kong Island (Guilford, 1997). In Tokyo, medium scale reclamations took place from 1860 to 1960 (Hamasuna et al., 1991). However, large scale of reclamation emerged after 1945 as the solution for the pressure of increasing population and the economical growth in many other countries. The history and

development of land reclamation in Southeast Asia were reported in the literatures.

Brand (1996) reported the latest projects while Guilford (1997) reviewed the history of reclamation in Hong Kong. Development of reclamation in Singapore was reviewed by Wei (1997). Aun (1998) described the recent and present planning of peninsula and island type of reclamation in Malaysia. Gouw (1997) and Ann and Yee (1997) reported recent major reclamation projects in Indonesia. In Taiwan, the reclamation activities were described in the governmental publications such as Kaohsiung Harbor Bureau (1971) and Research Institute of Transportation (1993). A review of reclamation in Philippines was outlined by Wang (1998). Hamasuna et al. (1991) described the history of reclamation in Tokyo. Some major island type reclamation for harbor facilities were described by Miyanaga et al. (1991). The above-mentioned literatures are only examples to show the awareness of the profession in this engineering discipline.

Land use of the reclaimed sites varied from residential area, recreational area, and industrial park to sanitary landfill. In the 1970's the size of the reclamation sites for housing purposes generally varied from 200 to 300 hectares. During the period between 1980's and 1990's, the scale of land reclamation in Southeast Asia became larger and larger. As shown in Table 1, the Chep Lap Kok Airport in Hong Kong was housed on a 920-hectare reclaimed platform which were formed by 206 million cubic meters of fills. For industrial developments, thousand hectares of reclaimed lands were created in Taiwan during the 1990's. The projects presented in Table 1 indicates that winning sands from marine source is a vital part of the reclamation projects.

Table 1 Major Reclamation Projects in Southeast Asia

City/Country	Project	Total Area of Reclamation, (hectare)	Quantity of Marine Fill, ($\times 10^6 \text{ m}^3$)	Total Quantity of Fills ($\times 10^6 \text{ m}^3$)	Year of Reclamation	Main Dredgers	Reference
Hong Kong	Chek Lap Kok Airport	920	76	206	1991-1992	Trailing suction hopper dredgers	Brand (1996), Oakeree(1992)
Osaka, Japan	Kansai Airport	511	2	178	1988-1991		Nakase(1987)
Singapore	Changi Airport	645	40	40	1976-1979	5 cutter suction dredgers	Choa (1980)
	Changi East Phases IA and IB	1550	210	210	1992-1997	3 trailing suction hopper dredgers	Choa (1996)
Taiwan	Changhua Industrial Park	3578	147	147	1996-2000	3 cutter suction dredgers	Seto et al. (1996)
	Mailiao	2250	74	74	1994-1997	2 plain suction dredgers	Kao & Elshout (1995)

A NEW METHOD USED IN COASTAL LAND RECLAMATION AT MAILIAO, TAIWAN

Background

This section is devoted to a successful method of dredging marine sand for land reclamation under difficult heavy weather conditions at Mailiao, Taiwan. The reclaimed land is for the use of the "Formosa Plastic" Company's petroleum cracking refineries. The operation took place approximately 60 km south of Taichung and comprises the construction of a port for seagoing vessels, dredging an estuary and creating 2250 hectares of new land that is about 3m above the sea level. The sandy fill was dredged from marine borrow areas up to 12 km away from the reclamation sites. The project began in July 1993 with a search for suitable dredging equipment by both the contractor and the owner. The first idea was to deploy a couple of big cutter dredgers, which had to meet the demanding local conditions. There were two marine borrow areas for this reclamation project. Borrow Area I contained 13 million m^3 in shallow water, which was 2 km from a river estuary. Dredging at this area was restricted to a depth of 8 m and the tidal range was approximately 2 m. The pumping distance between this borrow area and the site was ranging from 5 to 7 km. Borrow Area II, which the location for a deep water port, is approximate 4 km offshore and provided 61 million m^3 fills. The depth of the port is ranging from 16 to 21 m. The pumping distance was ranging from 1 to 7 km. The soils in these borrow areas were mainly silt and fine to medium sand.

The meteorological condition of the offshore area is severe. During the summer months (April to September) the surface of the sea is smooth, but there is a chance of an occasional typhoon. During winter months, a strong Northeast monsoon prevails accompanied with long heavy swell. The local dredging industry had the experience that

medium size dredgers can only work for between 100 to 120 days a year.

The nearest refuge harbors are Taichung, 60 km to the north, and a small fishing port, 50 km to the south.

Design Requirements

In addition to the unfavorable marine environment, the dredging fleet should satisfy the following requirements:

- 1) The project had to be completed within 4.5 years.
- 2) For future projects the dredgers would have to be deployed for sand winning approximately 10 km offshore. The seventy-four million m^3 fill of the reclamation project is barely 10% of the total volume to be dredged.
- 3) The dredgers must be able to work in both shallow and deep waters.
- 4) The dredgers had to be suitable for adoption at a later stage in order to level the bottom of the harbor.
- 5) The dredgers would have to begin working in early summer 1994 in order to enjoy the summer conditions as long as possible. This was probably the most difficult requirement, because it was July 1993 already when initiated the design of the fleet.
- 6) The new dredgers would have to deliver the highest possible output against the lowest possible price.

Plain Suction Dredgers

The solution for satisfying all those requirements was the deployment of plain suction dredgers. Against the odds, this solution was simpler than initially expected. The idea of building very large cutter dredgers was dropped, because this would require a long time for negotiations, extensive technical preparations, building and delivery. Deployment of readily available medium size cutter or wheel dredgers was out of the question, because too many craft would be

necessary, and they would be hampered by the 120 days a year operating limit. To save time, the solution had to be sought in optimizing existing designs and in the use of as many standard components as possible. After careful evaluation, a newly launched Dutch plain suction dredger, the "IJsselmeer", met the conditions of this project. The "IJsselmeer" dredger works excellently in the soil where only cutter dredger could work previously. In addition, the soil at Mailiao is even easier for the "IJsselmeer" dredger to dredge than the soils that the "IJsselmeer" dredger used to work in.

The major design concept of the plain suction dredgers follows those of the "IJsselmeer" dredger. The major dimensions and power plant of the dredger are shown in Table 2. An underwater pump is connected at the bottom of the ladder. The pump is driven by deck-mounted engines that operating through a pivoting gearbox. The pivoting gearbox is of heavy duty and moves with the ladder. The engines are easy to maintain because of mounted on the deck rather than mounted below the deck. Other merits of this type of dredger are high fuel efficiency, ease of control, longevity and relatively low cost. Booster pumps were deemed necessary to bridge the large pumping distance. Two pump drives were chosen of the type used in the Beaver 3800 cutter dredgers. The double walled pumps had to be modified to withstand an end pressure of 24 bar.

Table 2 Major dimensions and power plant of the dredger

Major dimension:	
Overall length	72.1 m
Beam	14.9 m
Depth at side	4.25 m
Average draught (approx.)	2.25 m
Max. dredging depth (approx.)	34 m
Diameter of the suction tube	700 mm
Diameter of discharge pipe	700 mm
Power plant:	
For the submerged dredge pump	1,752 kW
For the dredge pumps on deck	(2x) 1,908 kW
For the jet pumps	876 kW
For on board network generator and hydraulic pumps	876 kW
For the harbor set	105 kW
Total installed power	7,425 kW

Optimization of Design

In order to increase production and bring down the cubic meter price, the average annual operational days had to be doubled. The target became 240 or even 250 days. In other words, the dredgers had to be able to dredge under heavy sea weather. Experience with seaworthy stationary dredgers was limited. Statistics for the area indicated that 2.75m could be assumed as a significant wave height, with a period of 7 to 9 seconds, which happens to be a dangerous

long swell. If a craft could be designed to meet these conditions, only two dredgers would be needed for finishing the 74-million-cubic-meter fills in 4.5 years. Both the contractor and the dredger builder agreed to design the dredgers base on the conditions described previously with the considerations of winning sand from both shallow and deep water, optimizing the size of the craft, coupling the floating pipelines and providing ways for swell compensation for the suction pipe.

The design considerations of the suction pipe and the swell compensation system are as following:

- 1) The dredging operation was to begin in very shallow water.
- 2) Optimum production required to be able to dredging as deep as the authorities would allow. (Production of a plain suction dredger increases with the depth of the pit).
- 3) The system must be able to follow vertical and horizontal movements of about 10 m and yet retain enough stability to avoid production losses.
- 4) Compensation should preferably not be sought in the heavy wheel ladder, which would be complicated and hence prohibitively expensive.
- 5) The suction tube must be able to dredge through layers of consolidated silt.
- 6) The system should be able to survive the collapsing of deep pit.
- 7) The system must be able to free itself by continuing the dredging process as well as by pulling the suction tube free in a controlled manner and should not need emergency hoisting gear.
- 8) The system should be able to reduce the mixture concentration when pumping over long distance.
- 9) Servicing the suction head in heavy seas should be possible.
- 10) The system should be simple to operate.

Floating Pipeline

In order to fulfill above-mentioned requirements, special design features of the floating pipeline connection and the anchoring system were incorporated in the dredger design. Coupling the floating pipelines to a large extent dictates the maximum wave height in which the dredger can work. This could be done near the center of floatation. An additional advantage was that the pipeline would be well out of the way of the anchor cables and reduced the risk of damage significantly. The craft is designed to meet the Northeast wind on the stern, and the floating pipeline coupling meets the wind under a certain angle. The funnel-shaped support, built of anti-friction materials, made the coupling procedure easier and prevented kinks. The coupling can be used on the port as well as on the starboard sides. For working in heavy sea conditions, a quick coupling device and a heavy winch were incorporated. The heaviest anchor winch is on the stern. Calculations

Table 3 Case history of dynamic compaction for hydraulic sand

Site	Phase	Weight of Pounder W (kN)	Height of Drop H (m)	No. of Pass Per Grid	Spacing of Grid (m)	Total Energy (kN-m/m ²)	Max Depth of Improvement d _{max} (m)	Reference									
TAIWAN Mailiao	Working Panels	240	25	12-14	9	2820 Site I	9	Chung et al. (1995); Pan and Hwang (1995); Wu et al. (1996)									
		200	25	12-14	9	3420 Site II	9										
	Haifong	Trial Panel	240	20	11-33	9-12	3000	9	Yu and Hsu (1997)								
			240	25		9-12	5000	13									
			250	20	18	8	5625	12									
SINGAPORE Changi	Initial Phase	250	15			1250	6	Choa (1980)									
									Changi East	Phase 1A	230	25	10	6	1600	8	Choa et al. (1997)
											150	20	20	6	2350	8	

During the withdrawal of the vibroflot, granular backfill is very often placed into the ground through the annular void between the vibroflot and the ground so that compacted granular material is formed within a volume of soil compacted. When sand is used as backfill, the product is named sand compaction piles and when gravel is used, it is named as stone columns. On the other hand, there is a procedure that the compaction takes place in only one phase and without import of backfill material. This simplifies the operation. According to Debats and Sims (1997), depths up to 35m can be reached and both land and marine compaction can be carried out. In Taiwan, the vibroflotation technique is referred to the Sand Compaction Pile (SCP) method that uses ordinary vibratory hammers with pipe pile (Moh et al., 1981).

Table 4 summarizes the results of the vibroflotation technique in various reclamation projects in Southeast Asia that were reported by the professionals. The maximum depths of ground treatment range from 10m to 21m. Depends on the magnitude of the vibration energy, the spacing of the treatment point is ranging from 1.6m to 4.0m. The depth of ground treatment reached as much as 21m. Results of in-situ tests measured before and after compaction indicate the degree of improvement is as much as 300 %. Compared with the degree of improvement of 40 to 50 % that could be obtained by dynamic compaction, vibroflotation is a more efficient densification method.

Resonance Compaction

Vibrating probe methods for densification of hydraulic sand fill was adopted in Hong Kong (Hwang et al., 1996) and at Phase 1B of the Changi East Extension in Singapore (Choa, 1996; Choa et al., 1997). These methods utilized essentially vertical vibrations in the probe. Densification is achieved by using the resonance concept that was introduced by Massarch (1990). The vibrating probe excites the ground vibration at resonance frequency, thus amplifying the ground resonance and improving the efficiency of the compaction. According to Hwang et al. (1996), densification can be applied by the flexible probe for deep compaction, or by the rigid vibratory plate for shallow surface compaction. The vibratory probe system comprises a powerful hydraulic vibrator attaching to the top of a flexible probe to generate vertical vibration. Vibration sensors can be placed on the ground to measure the ground response. These measurements were sent to a computerized control unit that can adjust the vibrating frequency of the probe. The vibrating frequency is adjusted accordingly to the frequency that resulted in greatest ground vibration, which is also called nominal resonance frequency. Based on the experience of using the Resonance Compaction Method in Changi East Reclamation Phase 1B, Chao et al. (1997) concluded that the type of vibrator, spacing and duration of compaction and the selected frequency are important factors.

Table 4 Summary of case history of vibroflotation on hydraulic fill

Country/ Site	Vibroflot/Casing						Process	Max. Thick. of Fill (m)	Spacing Of Grid (m)	Assessment Tests				Reference
	Dia. (mm)	Leng. (mm)	Wt. (kN)	Ecce. Force (kN)	Amplit. of Vibrat. (mm)	RPM				CPT MPa		SPT N value		
										Pre- Comp.	Post Comp.	Pre- Comp.	Post Comp.	
<i>Hong Kong</i> West Kowloon Tai Ho Central	350	3500	21	300	23	1800	Wet	13	3.4-4.0	4-7	6-26			Debates and Sims (1997)
Chek Lap Kok	350	3500	22	450	32	1500	Wet							
<i>Singapore</i> Pasir Panjang				150 350	8-12 26			10	2.5 3.0	5-10 5-10	5-30 15-27			Aun and Yee (1997)
Changi East	350 360 350 400	3250 3300 3250 2900	22 25 25 24.4	280 330 450 290	23 28 32 25	1800 1800 1800 1775	Wet		2.5-3.0 2.4-2.6		15 15			Choa et al. (1997), Raju (1998)
<i>Taiwan</i> Mailiao	600	2500					Wet	17	1.9-2.4	3-6	7-11			Su et al. (1997),
Yung An	400						Dry	14	1.6-2.8	4-5	8-10	4-8	12-24	Chung et al. (1987)
<i>Indonesia</i> Arun	381	1860	18	100		1800	Wet	17	2.4			11-13	30-44	Gouw (1997)
Batam				400		3000	Wet	4-17	2.83	2-5	5-13			
Tarahan	400						Dry	21	1.8			2-4	6-11	

CONCLUDING REMARKS

Reclamation is a widely accepted method for obtaining land to house infrastructures, residential and commercial developments in Southeast Asia. For placement method, hydraulic filling using marine source is commonly used and is preferable than land-based source filling. Suction dredgers are widely used to win marine sand for reclamation projects. With well planing and designs, these dredging vessels can supply millions cubic meters of fill in a clean and effective manner. The custom built suction dredgers used for the reclamation project in Mailiao, Taiwan are excellent examples.

Densification is generally required to improve the strength of hydraulic fill and reduce its settlement. Many densification methods including dynamic compaction, vibroflotation and resonance compaction are successfully applied in reclamation projects in the Southeast Asia region. Quality control of the reclaimed lands can be done by establishing procedures and criteria for densification, and by using in-situ testing such as CPT and seismic methods to inspect.

Additional areas to be considered are: 1) Seismic effects should be given more consideration for reclaimed lands to prevent unexpected failure. The relative density of hydraulically placed fill may be about 60% at best, however,

the value could be lower than 20% (Jefferies et al., 1988).

Therefore, the susceptibility to liquefaction of a hydraulic fill land is very high during seismic loading. 2) The reclamation process would inevitably cause various impacts not only to the coastal area but also to the surrounding marine environment. Therefore, the operation of the reclamation should minimize water and air pollution, damage to aquatic habitat, shoreline changes, etc. The surrounding region should be carefully conserved and mitigation may be necessary during the land development. 3) Cost/benefits analysis is critical in the selection of the placement method and the subsequent treatment of the reclaimed lands. The Mailiao project in the west coast of Taiwan is an excellent example for selecting the custom-built equipment to speed up the filling, thereby saving time and cost.

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