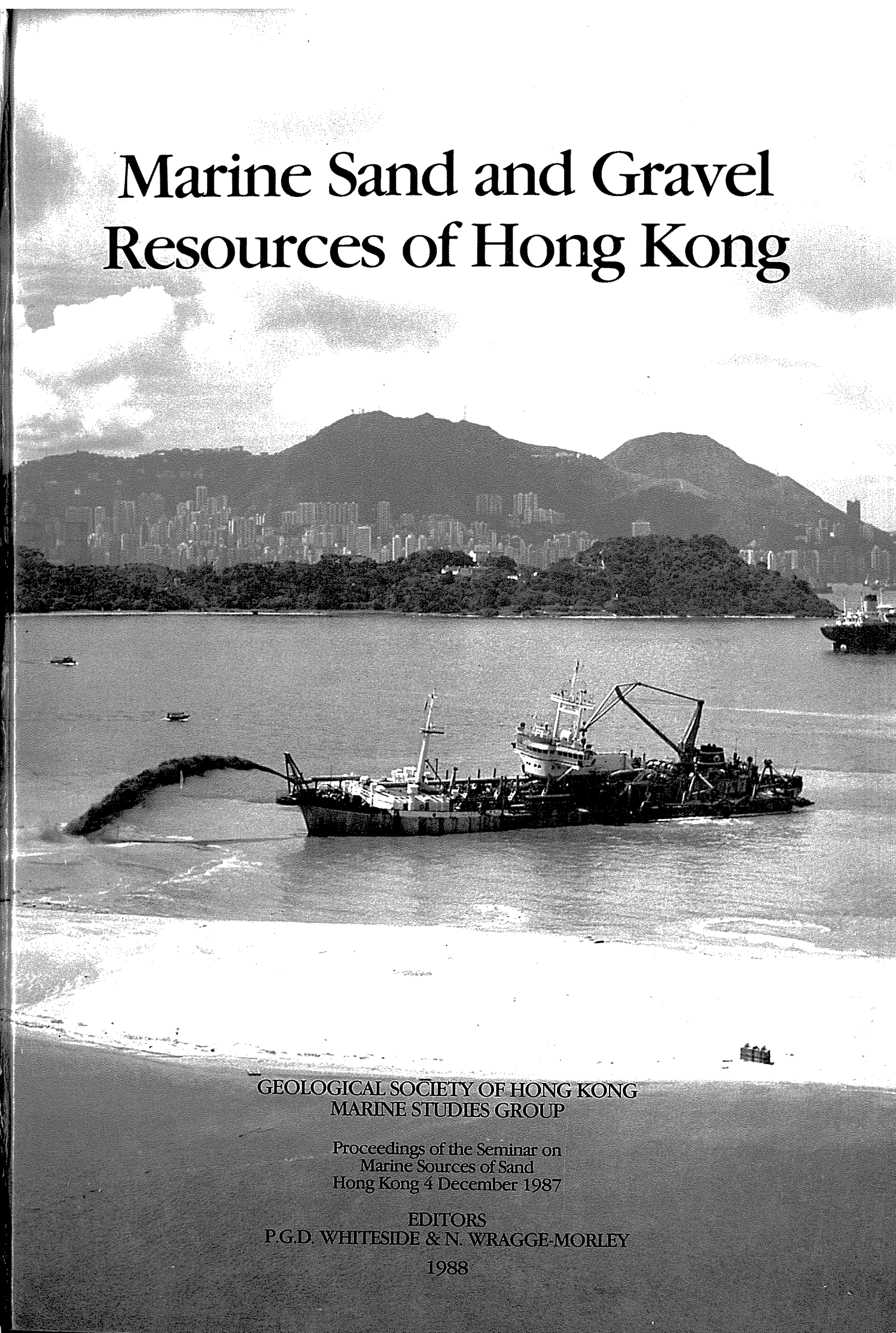


MARINE SAND AND GRAVEL
RESOURCES OF HONG KONG

EDITORS: P.G.D. WHITESIDE & N. WRAGGE-MORLEY

Marine Sand and Gravel Resources of Hong Kong



GEOLOGICAL SOCIETY OF HONG KONG
MARINE STUDIES GROUP

Proceedings of the Seminar on
Marine Sources of Sand
Hong Kong 4 December 1987

EDITORS
P.G.D. WHITESIDE & N. WRAGGE-MORLEY

1988

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ISBN 962-7320-01-3
Marine Sand and Gravel Resources of Hong Kong

This publication is available from :
The Secretary, Geological Society of Hong Kong
c/o Dept. of Geography and Geology
University of Hong Kong
Hong Kong

Cover Photograph : The trailer suction hopper dredger, HAM 308
discharging marine sand for the formation
of Container Terminal 6, Hong Kong, 1987.

Photo courtesy of Hong Kong International
Terminals Ltd.

Marine Sand and Gravel Resources of Hong Kong

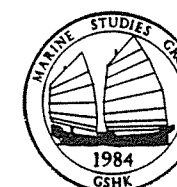
Proceedings of the Seminar on
Marine Sources of Sand
held in Hong Kong on 4 December 1987

Organised by the
Marine Studies Group
of the
Geological Society of Hong Kong

Editors
P.G.D. Whiteside & N. Wragge-Morley



Geological Society of Hong Kong
Marine Studies Group
May 1988



FOREWORD

This volume consists of 13 invited papers presented at a seminar on "Marine Sources of Sand", together with written discussions and contributions received after the event.

The seminar on "Marine Sources of Sand", held in Hong Kong in December 1987 was the product of efforts over a number of years by members of the Marine Studies Group of the Geological Society. The founding of the Marine Studies Group at the instigation of Wyss Yim and myself, came after the 1983 Geological Society Conference on the Surficial Deposits of Hong Kong. Our aim was to encourage interest in marine Quaternary geology, by establishing a forum for scientific discussion of the subject.

Working hand-in-hand with the Geological Survey, the Group took as its first objective the creation of strato-type localities. These are locations where the geological succession is known in detail, and with which other sites can be compared. Initially this involved compilation of data from sites with which Group members were personally familiar. Following this, arrangements were made for continuously sampled marine boreholes to be put down under close, expert supervision. This was achieved by the combined efforts of several members of the Marine Studies Group, and with the permission of private owners and the public works controlling officers. Borehole samples from Chek Lap Kok, Junk Bay and Deep Bay were procured in 1984 and 1985, for study by the Geological Survey. The samples were carefully examined and the sedimentary sequences recorded; palaeontological analyses were made for dating purposes and to aid the determination of depositional environments.

At about this time, Russell Arthurton was studying the present day tidal scour channels of the Pearl River mouth, by means of bathymetric maps made from Admiralty Charts. In early 1985, he proposed research themes to explore the evolution of these channels as the sea rose to its present level during the Holocene transgression. This seminal work, which was outlined in a short paper published in the Proceedings of the First Seminar of the Marine Studies Group in 1985, together with Colin Dutton's work in Deep Bay, has led directly to the development of geological models of sand occurrence and to the discovery within the last couple of years of further vast sand and gravel deposits.

The realization that the time was ripe for a second Marine Studies Group Seminar, this time on marine sources of sand, came late in 1986, when our expectations of large reserves of sand were being confirmed by drilling and geophysics, and actual exploitation for Container Terminal 6. A programme of technical meetings, culminating in a seminar, was therefore planned in early 1987, and since then the entire business has been managed by Peter Whiteside, with a sub-committee of one.

The seminar proved to be of great interest, being attended by a wide audience of about 170 persons, representing civil engineering consultants and contractors, government, dredging companies, aggregate suppliers and ready mix concrete manufacturers, academics and shipping people.

This book will therefore be a useful record of current understanding in 1987 in Hong Kong of marine Quaternary geology, offshore exploratory techniques, specifications for aggregates and for reclamation fill, dredging methods and their environmental implications, and the local market for marine dredged sand and gravel. Its publication comes at the beginning of what may prove to be a new era in the exploitation of indigenous raw materials for Hong Kong's construction industry.

Andrew Malone

Chairman
Marine Studies Group

Hong Kong
March 1988

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PAPERS

Marine fill in Hong Kong - a 35-year resume

C M Guilford

Scott Wilson Kirkpatrick & Partners, Hong Kong

SUMMARY Following the extensive use of marine sand from deep deposits in Hong Kong harbour during the redevelopment of the international airport at Kai Tak some thirty years ago, granular material has since been obtained for other major civil engineering projects and for fine aggregate needed for building purposes, mainly from widespread small inshore deposits. Only recently has attention again been focussed on extracting large quantities of granular marine material, in particular from the Territory's western waters, for general reclamation purposes.

Aspects covered in the paper include site exploration, sources and uses of marine fill, dredging and handling methods (including their effects on the quality of filling) and problems, including environmental, that have arisen in the past during dredging and filling.

Introduction

Granular material obtained from the Territory's waters was used extensively for the Kai Tak international airport works in Kowloon Bay in the 1950s and, subsequently, smaller amounts were obtained from scattered seabed deposits for use in such projects as the Plover Cove main marine dam, the Kwai Chung development, the High Island cofferdams, Tuen Mun New Town reclamation and the Chek Lap Kok test embankment. These seabed deposits also provided one of the sources of fine aggregate suitable for building purposes for the now defunct Government Sand Monopoly and, to a very limited extent, for water treatment filter beds.

Generally, marine filling has been won in the past using grab and cutter-suction dredgers from relatively shallow inshore deposits not overlain by mud. The notable exception until very recently was in the area off Hung Hom bay in Hong Kong harbour where some 5.5 million cu m of mixed, essentially granular, deposits were removed to depths down to about -22m PD for the Kai Tak airport reclamation by two bucket dredgers supplemented by a small drag-suction hopper dredger which could dig material somewhat deeper. Only in 1987 has use been made of much larger plant, namely large- and medium-sized trailing-hopper suction dredgers in connection with the Terminal 6 development at Kwai Chung which has involved extracting from depths up to around -30m PD some 8 million cu m of granular material from the seabed to the west of Tsing Yi.

As will be discussed, the quality when deposited of granular materials extracted from marine sources depends much more on handling methods, eg type of dredger used and method of deposition, than on the quality of the in-situ material prior to dredging.

Due to the apparent lack of readily accessible sand, increasing use has been made since the early 1970s of land-based filling as an acceptable alternative to marine sand for seawall foundations. Nevertheless this trend is

now likely to reverse, not only for seawall construction but also for general reclamation, with extraction from the large-scale predominantly granular deposits now established to be located in deeper waters offshore.

In the past, marine mud generally has been treated as a waste product and dumped at sea in numerous areas. The possibility of forming land with mud as the sole or main filling material is touched upon briefly.

Investigations

Methods

The usual methods adopted for investigations of granular marine deposits in Hong Kong have been:-

- (i) Desk study involving an examination of Admiralty charts, geological maps, aerial photographs, existing borehole information and other records
 - (ii) Simple probing, for instance with extended ranging rods in shallow water, to find the approximate extent of any deposit
 - (iii) Marine boreholes sunk from rafts or stagings in shallow water, or from barges in deeper water. Jack-up pontoons have become available in Hong Kong in relatively recent times
- and (iv) Geophysical surveys which have only recently been implemented specifically for locating sand deposits.

Spacing of exploratory boreholes

The spacing of holes has varied considerably. For instance, in the original Kai Tak investigations in the 1950s, about fifty borings were made representing on average one hole per 20,000 sq m of seabed or, on a volumetric basis, about 120,000 cu m of production per hole.

For the Plover Cove marine dam, some 33 holes were sunk in six shallow inshore areas which represented about one hole per 50,000 cu m required. Subsequently in the sand search for the Tuen Mun New Town development in the mid-1970s over 130 holes were made in the four borrow areas used, which yielded some 30,000 cu m per hole. A further 60 holes were sunk in other areas which were discarded as uneconomic to work.

Sampling

Undisturbed sampling in marine sands is difficult unless some fines are present to act as a binder; however Mazier and Bishop sand sampling methods have been used successfully. Complete bulk samples of granular materials can be obtained simply, namely by conserving all material trapped during 'shell' boring, the fines/water mixture being carefully drawn off to determine the fines content by laboratory sedimentation. The geotechnical characteristics of granular marine soils to be dredged have generally been determined by visual inspection of disturbed samples, conventional classification and in-situ Standard Penetration tests.

Quality requirements

On projects undertaken up to the late 1960s, specifications often called for sand deposited under seawalls to be relatively clean with a fines content less than 15%. Subsequently, however, with the depletion of readily accessible inshore sea-bed surface sand deposits around the Territory, the use of marine sand for civil engineering purposes was severely restricted and other materials were substituted. For instance, at the Kwai Chung container terminals in the early 1970s, decomposed granite was used for seawall foundations, a higher fines content of up to 30% being acceptable. Marine sand, however, continued to be used to a limited extent until the early 1980s at Tuen Mun New Town for seawalls and seabed blanketing but, very recently, large quantities have been extracted for general filling for the Terminal 6 reclamation, both with a 30% fines criterion after handling. Limited amounts of shell have generally been permitted in filling.

Field quality tests

In practice the material in any marine borrow area is likely to be very variable and, moreover, the quality loaded into barges or the hoppers of trailing-suction dredges depends to a large extent on the method adopted for its extraction. To determine the fines content of material loaded into barges, a quick and reliable method using a pycnometer (essentially a large-sized specific gravity bottle) was developed for sand at Kai Tak and later used at Plover Cove for classifying decomposed rock filling. Tests carried out on barges, involving only weighing and sieving which could be completed in about 15 to 25 minutes depending on the fines content, ensured that the quality of each barge-load was known with an acceptable degree of accuracy prior to deposition.

Sources & uses of granular fill

Sources

Until the mid-1970s marine sand for building purposes, civil engineering works and water treatment filter beds has generally been obtained from small-sized deposits located in a large number of widespread inshore areas. Nevertheless some large deposits were known to exist, namely Tai Po bay where about 6 million cu m of sand was located, Hung Hom bay from which 5.5 million cu m was extracted, Sai Kung Hoi and High Island each with some 4 million cu m (the latter now submerged within the reservoir area), Tung Chung off northern Lantau where about 3 million cu m was available and in the People's Republic of China. Known deposits larger than 100,000 cu m situated in territorial waters in the period 1950-1975 are indicated in Fig 1.

By the mid-1980s the search for major marine deposits had got underway and large deposits were confirmed in the Territory's western waters, off Tsing Yi, in Hong Kong harbour and its eastern approaches. These deposits and others containing over 500,000 cu m, which were known to exist at some time during the years 1975-1985, are shown in Fig 2.

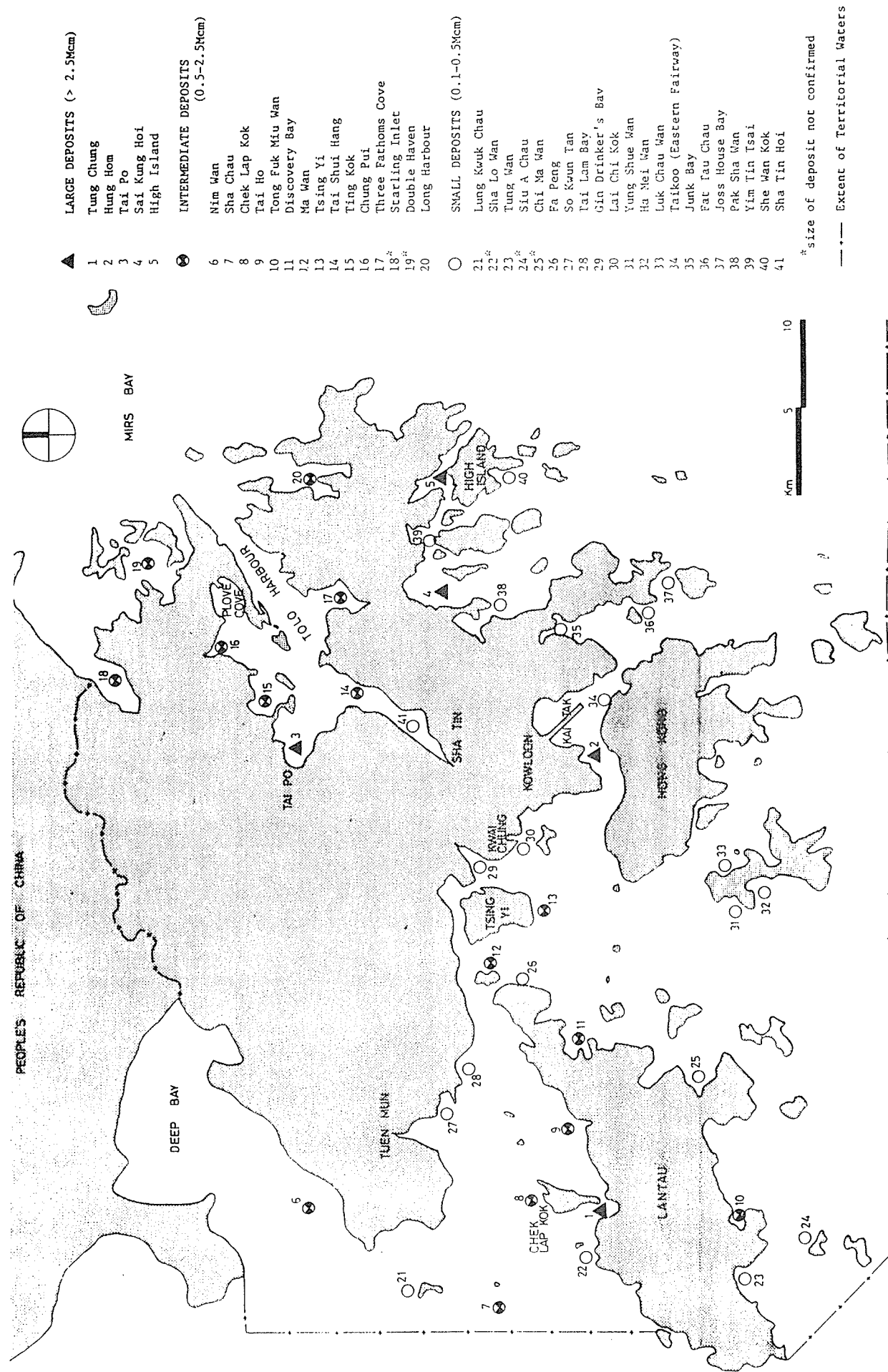


Figure 1. Known marine sources of fill : 1950 - 1975

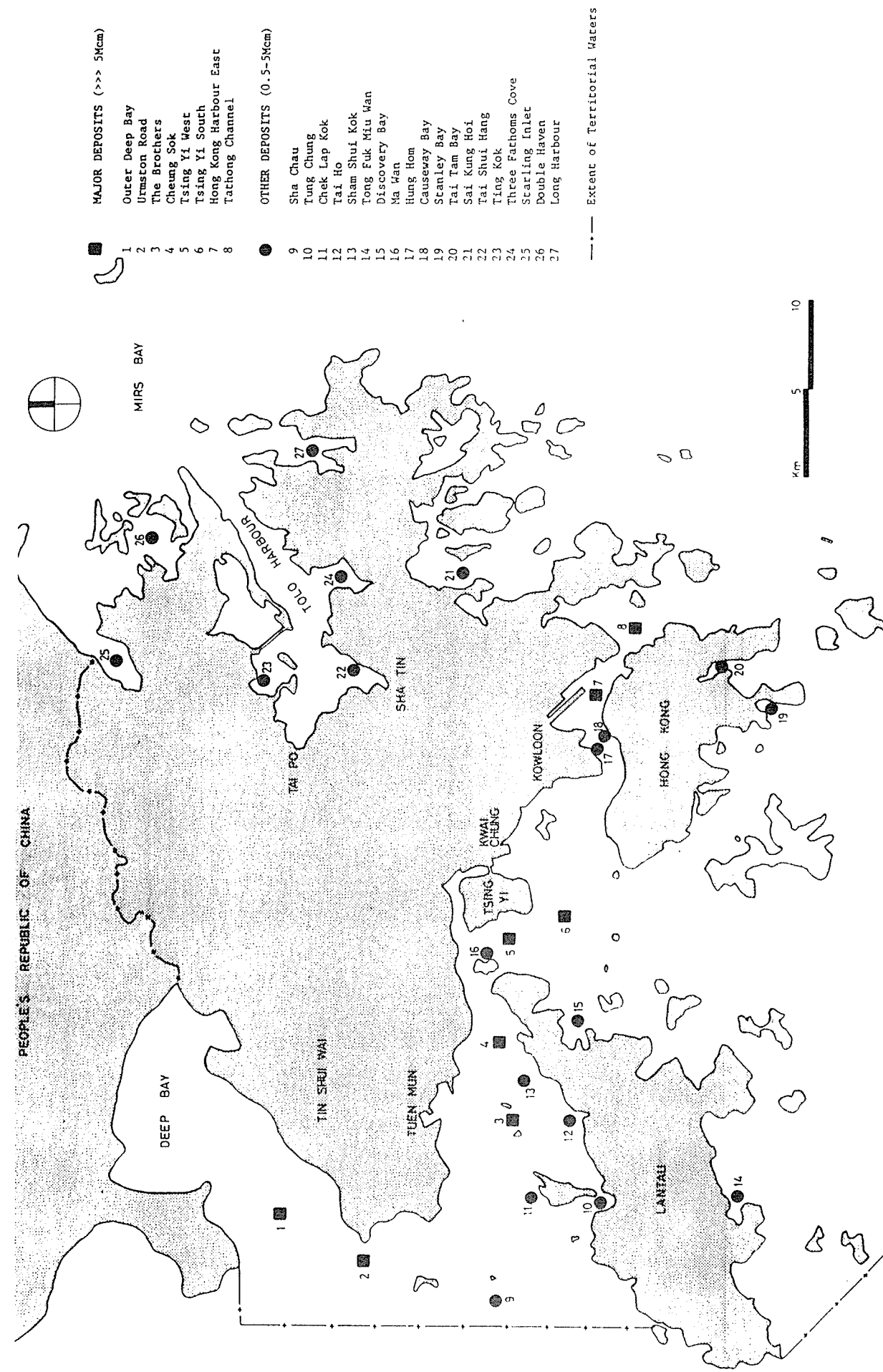


Figure 2. Known marine sources of fill : 1975 - 1985

Building sand

Until the late 1960s, the relatively few better quality deposits of sand were identified as suitable for building purposes and generally reserved for the Sand Monopoly contractor who offloaded material at depots at North Point on Hong Kong Island, Cheung Sha Wan in Kowloon and Ho Tung Lau near Sha Tin in the New Territories. Materials were dredged from sheltered inshore areas, eg Tung Chung, Tai Lam bay, Sha Tin Hoi and nullah outfalls. Substantial quantities were also dredged from the waters adjacent to the northern and eastern shores of Mirs Bay under special arrangements with the authorities in the People's Republic of China.

The largest deposit identified was in Tai Po bay (with some 6 million cu m in situ). However, as Tai Po was then the last known major source in the Territory of readily available natural building sand, its use in the Plover Cove marine works was not permitted. It is somewhat ironic that a decade or so later it was sterilized by the reclamation for Tai Po New Town.

Civil engineering works

Soon after the end of World War 2, substantial quantities of sand were extracted from the fairway in Hong Kong harbour off Hung Hom bay and used for the construction of the Causeway Bay typhoon shelter, the adjacent reclamation which is now Victoria Park and for the extensive Kai Tak airport reclamation in Kowloon Bay.

For subsequent civil engineering works, the poorer quality, mostly shallow, inshore deposits have had to be worked, principally off Sha Chau and Lung Kwu Chau, in various locations along the northern and eastern shores of Lantau, So Kwun Tan bay, off Tsing Yi, Joss House bay, in the Tolo Harbour area and near High Island, the exception being the deep deposit worked recently to the west of Tsing Yi.

Quantities of filling extracted from marine sources for some major projects undertaken to date are:-

	Quantity (M cu m)	Sources
Kai Tak Airport	7.5	Hung Hom: Tsing Yi South: Fa Peng: Joss House Bay
Plover Cove Marine Dam	2	Tai Shui Hang: Ting Kok: Chung Pui: Three Fathoms Cove
Tuen Mun New Town	3.5	Tung Chung: Sha Chau: Chek Lap Kok: Lung Kwu Chau: So Kwun Tan
Kwai Chung Container Terminal 6	8	Tsing Yi West

Filter beds

Another use for marine sand has been for water treatment filter beds. In view of the very tight grading and quality requirements, only limited sources of acceptable material could be located at the time of the Plover Cove investigations to meet the needs of the Silvermine Bay and Sha Tin treatment works, namely at Chung Pui in Plover Cove, the sand spit at Sha Lo Wan off

north-western Lantau and an area to the north of Sui A Chau, Soko Islands. Even then, to obtain an acceptable quality material, sand had to be processed by means of a hydraulic classifier which was an expensive operation and resulted in considerable wastage. As it was not possible to locate from marine (or land) sources suitable deposits of naturally occurring pebbles, also for use in the filters, these had to be imported in bags from Japan.

Dredging & handling methods

Dredging plant

Up to 1986, most of the dredging for granular marine filling had been undertaken using four types of dredgers, namely:-

	Maximum Depth (mPD)	Monthly Output ⁺ (cu m)
Bucket (or ladder)	-22	230,000
Drag-suction hopper (0.7m dia suction; 1000 cu m hopper; 3 km haul)	-26	90,000
Cutter-suction (0.6m dia suction)	-14	70,000
Grab	varied ⁺⁺	varied ⁺⁺⁺

⁺ Double-shift working

⁺⁺ To virtually any depth

⁺⁺⁺ Typically 40,000 cu m/month might be expected for a 2.5m capacity grab

Ancillary equipment needed to complement the dredgers (except the drag-suction type) includes varying types of barges, tugs and floating pipelines.

This year (1987), however, saw for the first time in Hong Kong large- and medium-sized trailing-suction hopper dredgers extracting granular material from a major marine borrow area; their basic characteristics are:-

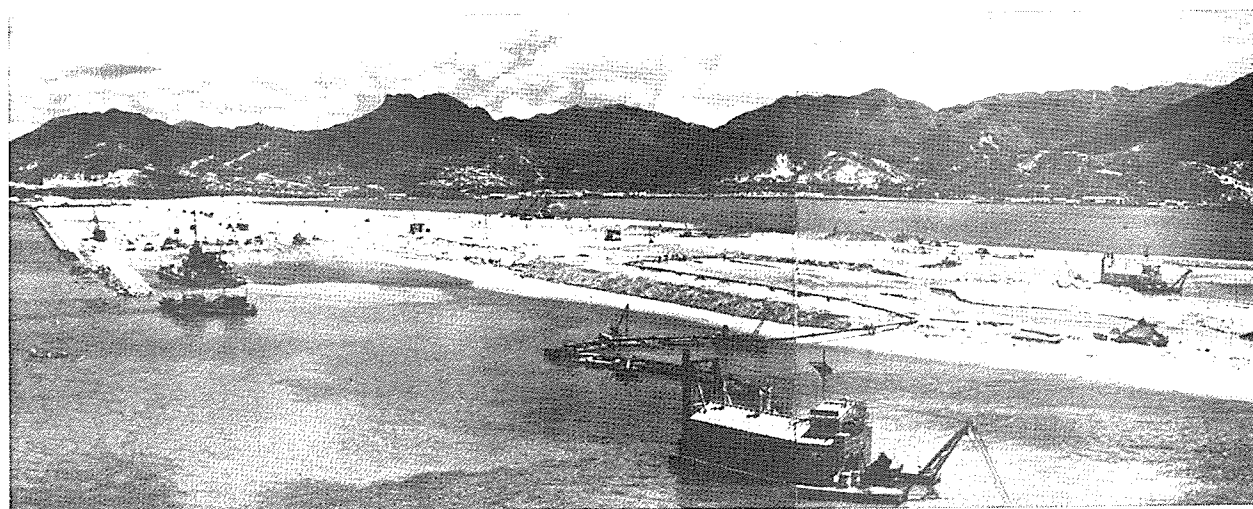
	Depth ⁺ (mPD)	Monthly Output ⁺⁺ (cu m) Dumping Pumping
Large (Twin 1.1m dia suction; 8200 cu m hopper; 6km haul)	-30	1,000,000 700,000
Medium (Twin 1.0m dia suction; 4700 cu m hopper; 6km haul)	-32	700,000 500,000

⁺ If static, dredging depths could be increased two-fold or more, with

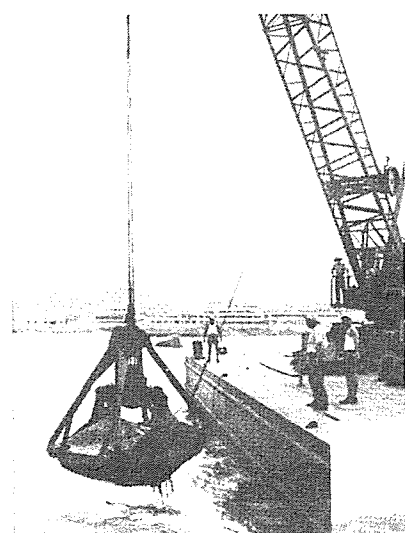
⁺⁺ modifications to suction pipes

⁺⁺⁺ Double-shift working

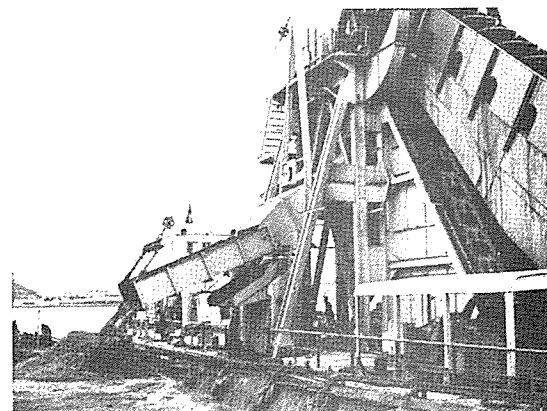
The great advantage of this type of equipment is that it is self-contained and can operate in exposed offshore locations. Moreover, although unable to dredge in confined spaces whilst under way, it does not sterilize large areas of water with mooring cables, floating pipelines, etc, particularly important when dredging in or adjacent to major shipping lanes.



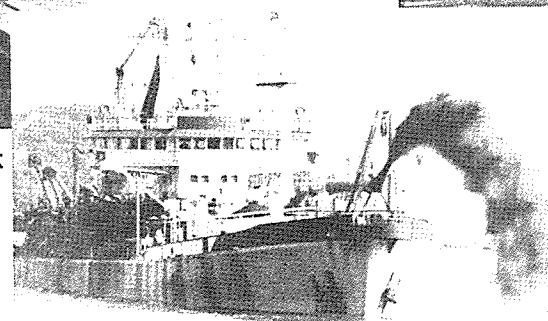
Cutter-suction dredgers pumping sand from stockpiles, Kai Tak



Grab dredger, Kai Tak



Bucket dredger 'Espace' Hung Hom Bay



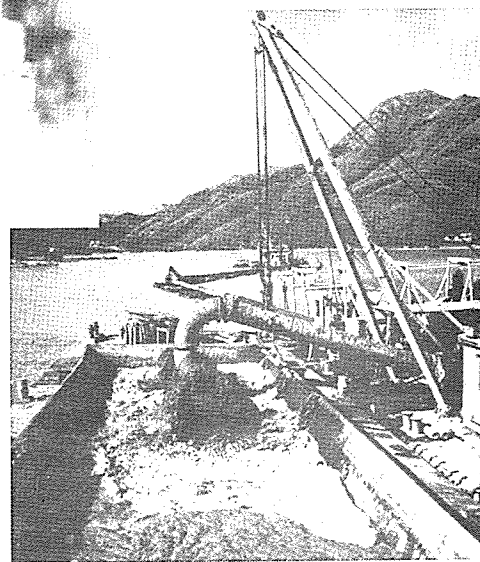
Trailing-suction hopper dredger 'Ham 308' Kwai Chung



Drag-suction hopper dredger 'Maitena' pumping sand, Kai Tak

Dredgers in Hong Kong

Figure 3.



Pumped sand discharging into barge, Chung Mei, Plover Cove

Some photographs of various types of dredgers in operation in Hong Kong are shown in Fig 3.

Survey control methods

Until recently, positioning of marine plant was controlled by such methods (or combinations) as twin back and front markers set up on land or in the sea, moored pontoons, tabbed lines strung between piles, land-based theodolite stations (often using visual signalling) and on-board sextants whereas nowadays, in particular on major projects, computerized electronic positioning is used. Underwater depth measurement devices have included traditional lead lines, sounding plates and echo sounders (recent types often with multi-frequency capability to detect more accurately "loose" materials, eg liquid mud). Side-scan sonar equipment, supplemented as necessary by diving inspection, has sometimes been used to detect underwater obstructions, eg rock protrusions, wrecks, abandoned anchors, and for trench profiling.

Handling

Sand extracted by grab or bucket dredgers and deposited directly from hopper barges into the works will essentially retain its in-situ borrow area composition with minimal loss of fines, which may be an advantage when environmental standards require a low level of turbidity.

Subject to turbidity constraints, suction dredging and hydraulic filling is attractive inasmuch that the grading of indifferent material can be improved significantly due to losses of fines, during both extraction and deposition.

For instance at Kai Tak, material containing more than 25% fines (some of it above 45%) was dredged by bucket dredgers and deposited in temporary stockpiles adjacent to the reclamation. It was then pumped with suction dredgers into position under pavement areas where the retained fines were less than 5%. Nevertheless care had to be taken in positioning discharge points to ensure that the washed out fines were not deposited in areas which would have been detrimental to the works. Much of the sand pumped above +3m PD achieved the specified BS density of 90% without compaction by land-based plant.

Sand deposition by controlled pumping, for example at Tuen Mun, has been very effective in building up uniform layers of free-draining material immediately overlying the weak sea-bed mud, thus avoiding the formation of mud waves or mud 'eruptions' that have proved troublesome on some projects, for instance beneath the Sha Tin racecourse and in certain back-up areas of the Kwai Chung container terminals. At High Island the areas between the rockfill bunds forming three of the cofferdams were filled hydraulically with material dredged from the seabed under the foundations for the dams. To avoid disturbance of the marine mud underlying the Chek Lap Kok trial embankment, sand was deposited hydraulically over the seabed; it also acted as the drainage outfall for the underlying plastic band and sand drains that were installed at close centres to accelerate consolidation of the mud. Prior to sand deposition for Terminal 6, all soft seabed material was removed to avoid potential problems associated with the marine mud.

Volumetric estimates of marine fill requirements must include adequate allowances for settlements, tolerances, pumping losses, over-dredging and deposition (eg dumping) losses. Experience on some projects has indicated measurement volumes incorporated in works of the order of 20-30% less than those extracted from borrow areas.

Adverse factors associated with plant

A disquieting feature of dredging for granular materials in Hong Kong is the abrasiveness of the local sand, due to angularity and hardness of the mainly quartz particles which have been transported for only short distances and consequently with little or no rounding action. In the then clearer eastern waters around Tolo Harbour, coral also has proved very abrasive. As a result, dredging costs have increased due to excessive wear, at Kai Tak on the manganese-steel lips of dredger buckets and at both Kai Tak and Plover Cove in the cutter heads, pumps and pipelines associated with suction dredges working in granular or corally deposits.

Problems were experienced at Kai Tak with joints in the floating pipelines and at their connections to dredgers for which, initially, inadequate provision had been made for movements arising from wave action.

Dredging in locations that have been affected by hostilities, as has been the lot of Hong Kong, can sometimes be hazardous due to the presence of unexploded bombs, etc which have remained undetected prior to the start of extraction. Wartime records can sometimes help in assessing the potential risk in a particular area. Fortunately no accidents on this account have been recorded.

Environmental

Apart from turbidity and its effects, concern has been expressed in the past regarding noise pollution, in particular around the Hong Kong harbour area, created by large items of dredging plant which normally have to be worked on a 24-hour basis six days a week.

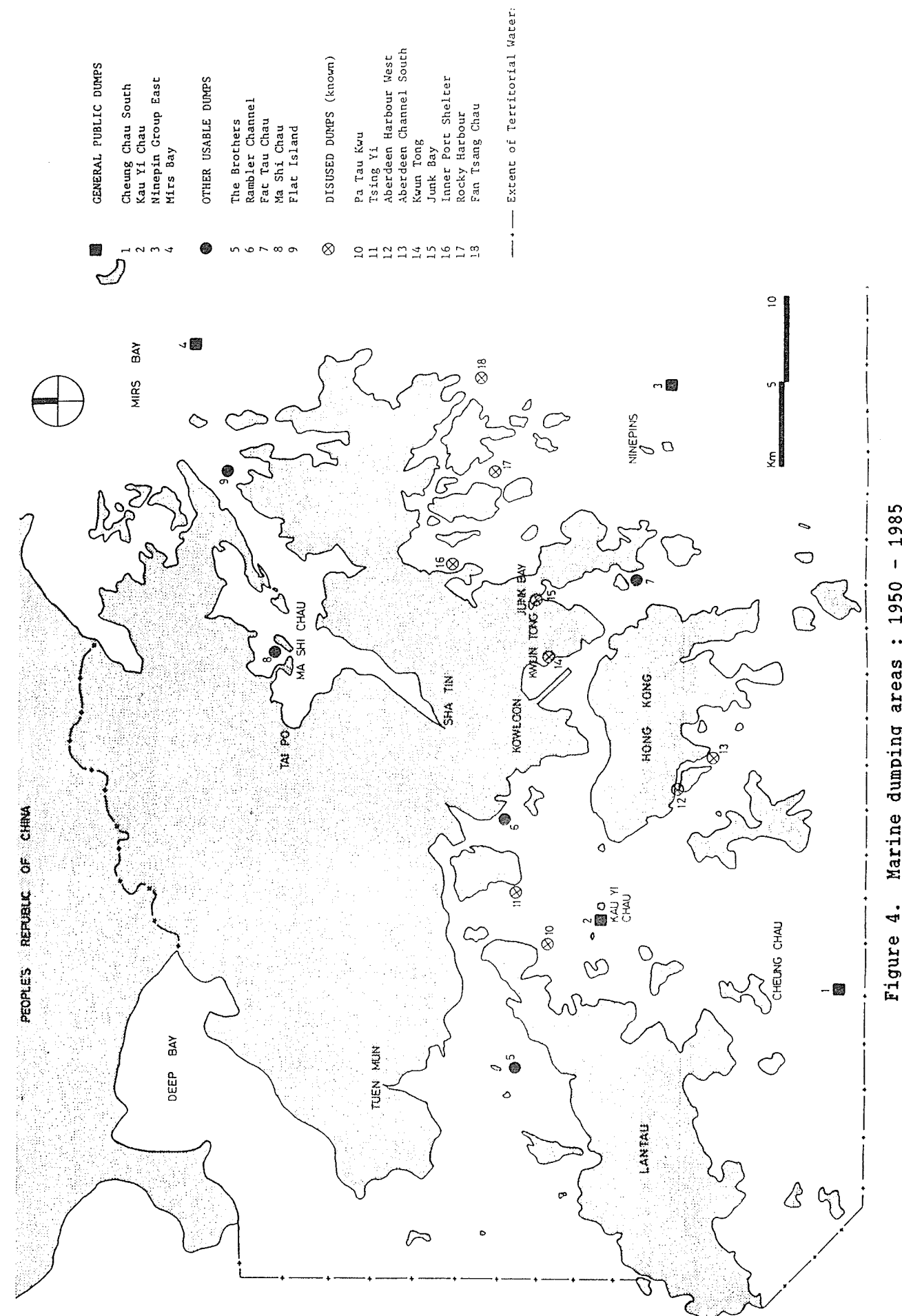
In remote areas of the New Territories, various problems have been experienced with villagers and others, eg understandable fears that inshore dredging will affect the natural protective beaches adjacent to their homes thus increasing the risk of damage during typhoons, effects on fishing and mariculture, and the risk of destruction of items of archaeological or ecological interest.

Mud filling

In the past, dredged mud generally has been considered as a waste product and disposed of at sea in a multiplicity of dumping areas - see Fig 4. The only significant use of mud for filling in Hong Kong has been in connection with the original Kai Tak runway works in the mid-1950s. In the early stages of construction some of the mud removed was deposited adjacent to the Shell oil depot in the Kwun Tong reclamation, most of which was being formed with domestic refuse from the urban areas. The remainder (over 1.5 million cu m) was dumped in the northern area of Junk Bay, some of which is being incorporated into the reclamation now in progress.

The future

With the grandiose schemes now being proposed or about to be implemented, for instance urban reclamations arising from the SHRUG studies, the Tin Shui Wai land reclamation, Kwai Chung Terminal 7, and the new port and airport development proposals, several hundreds of millions of cubic metres of filling materials, whether they be sand or decomposed granite, are likely to be needed over the next 10-20 years. Most of them will probably be won from marine



sources either within Hong Kong waters, eg the harbour area and its south-eastern approaches, off Tsing Yi and the western territorial waters, or outside in the Pearl River estuary (eg the Nei Ling Ting bank).

Large-scale marine borrowing operations, in particular when located away from shipping fairways or airport flight approaches, can be attractive economically and to a large extent avoid many of the major environmental problems (eg noise, dust and further traffic congestion on the already overcrowded roads) that are normally associated with excavations in land borrow areas.

In the future, formation of land with surplus marine mud as the principal or sole filling material should be considered and, if advantageous, adopted as an on-going long-term investment as has been achieved successfully in the Netherlands and other countries using carefully controlled deposition and 'ripening' methods. The 5.5 million cu m of mud dredged from the foundations of the Plover Cove marine dam, which was deposited nearby in the sheltered waters adjacent to Ma Shi Chau (see Fig 4), could perhaps form the lower portion of such a reclamation. Nevertheless implementation would need a fundamental change in attitudes to land formation planning, investment and the time interval between decision making and availability. The seabed portion of marine muds in which significant concentrations of chemical contaminants are present, eg those dredged from polluted harbour waters, would need to be excluded from the upper zones of finished reclamations. Furthermore, even with limited contamination, the top layers of the newly-formed ground would need careful study to determine the effects on flora and fauna, in particular if the proposed usage were for agricultural purposes.

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Review of Aggregate Supply in Hong Kong

O.G. Earle & A.G.S. Evans

Geotechnical Control Office, Hong Kong Government

SUMMARY The development of Hong Kong over the past 20 years has resulted in a massive demand for aggregates. This paper reviews the supply of aggregates to the Territory and describes how the pattern of supply has changed from one of self-sufficiency within the Territory to one of increasing dependence on producers in the Peoples Republic of China.

Introduction

Hong Kong is one of the most densely populated places in the World with a population of almost six million people occupying a land area of only 1,060 sq. km. Despite the limited land resources, an absence of most raw materials and the severe overcrowding, Hong Kong is a leading exporter of manufactured goods as well as being one of the World's major financial centres.

An increasing population and a growing economy over the past 20 years has led to spectacular growth in housing, commercial and industrial development. Investment by Government and the private sector in the Territory's infrastructure has created periods of intense activity for the local building and construction industries.

Concrete is the most commonly used building material in Hong Kong. To meet the needs of the concrete supply industry, considerable quantities of processed stone are required each year. For example, in 1987 the Territory's total consumption of sand and aggregate is forecast to be 18 million tonnes, of which 15 million tonnes will be used in the production of concrete.

Until 10 years ago, all processed stone, usually in the form of granitic aggregates, was obtained from quarries and rock processing sites located in Hong Kong. However, from the late 1970s, additional supplies of aggregates were obtained from quarries in the Special Economic Zones (SEZ) of the People Republic of China (PRC). It is estimated that in 1987, imports will account for around 44% of the Territory's demand for aggregates, whereas 10 years ago the only materials obtained from the PRC were small quantities of marine dredged sand.

The rock processing industry in Hong Kong produces coarse and fine aggregates primarily to suit the requirements of the ready-mix concrete suppliers. Whilst the use of river sand, imported into Hong Kong from the PRC, has increased over the last 10 years at the expense of the marine dredged sand, the overall quantity of natural sand imported into the

Territory has remained static. Consequently, natural sands have lost market share.

Consumption of Aggregates & Sand

The phenomenal growth in the development of Hong Kong has created periods of intense activity for the Territory's building and construction industries, which in turn have made considerable demands upon the suppliers of building materials and aggregates. Since the 1960s, the Government and the private sector have invested heavily in the development of the Territory's infrastructure in order to keep pace with an increasing population and an expanding economy.

The growth in Hong Kong's population since 1955 is shown in figure 1, which also shows the Territory's consumption of aggregates and sand. The population has increased since the 1950s at an average rate of an additional 100,000 persons each year. Although the graph of population growth does not highlight the years in which Hong Kong experienced massive influxes of immigrants from the PRC, it can be seen that the population has almost doubled since 1960.

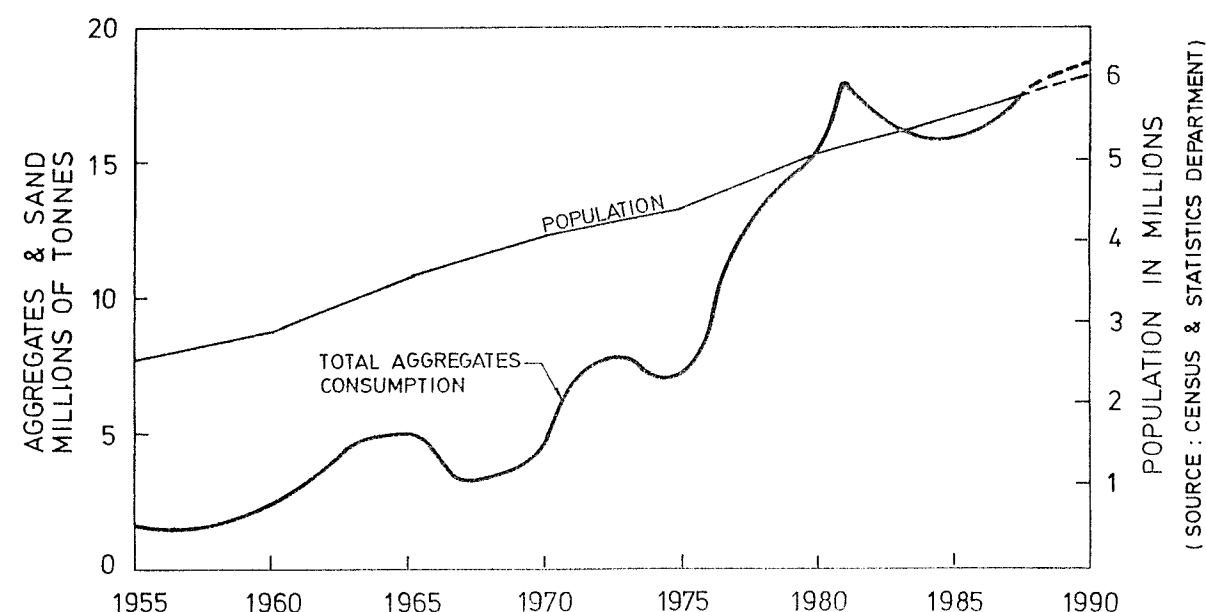


Figure 1 - Consumption of Aggregates and Sand and Population Increase 1955-1990

The growth in the consumption of aggregates has increased at a much faster rate than that of the population - an almost ninefold increase since 1960. The level of aggregate consumption was dictated by the pace of development and construction activity which reflected the level of Hong Kong's economic activity.

The first of Hong Kong's post war building booms occurred in the early 1960s. This led to severe shortages of aggregates, the result of which was a review by the Government in 1965 of the manner in which quarry concessions were granted. Government then embarked upon a programme of awarding quarry concessions through open tender. Though the number of quarries was eventually rationalised to six, each quarry concession (the contract quarries) contained a guaranteed a minimum tenure of 10 years with proven rock reserves. It became Government policy that the main sources for the production of aggregates within the Territory should be provided by the contract quarries.

During the mid 1960s political instability in the PRC slowed the level of building activity in Hong Kong, which resulted in a dramatic reduction in the demand for aggregates. However, a recovery quickly followed and Hong Kong entered a period of sustained economic growth and a programme of building new public housing, roads, hospitals and schools was initiated. The worldwide oil price related recession of 1973 contributed towards a slowdown in the Territory's development but from 1975 to 1982 Hong Kong enjoyed a period of phenomenal economic growth resulting in an increased expenditure on public works and privately funded property development. The demand for aggregates expanded from only 3 million tonnes in 1967 to a peak of 18 million tonnes in 1981. To put this growth of building activity into perspective, the consumption of aggregates per head of population increased from 0.75 tonne in 1967 to 3.4 tonne in 1981 notwithstanding the 50% increase in the population.

Hong Kong encountered a well publicised property slump in 1983. However, expenditure on public works was largely maintained and by 1985 interest in private sector funded property development had revived. The consumption of aggregates in 1987 is forecast to be 18 million tonnes, almost equivalent to the record year of 1981.

Supply of Aggregates

Since the mid 1970s Hong Kong has been provided with aggregates from the following four sources :-

- 1) contract quarries and rock crushing sites,
- 2) site crushers, i.e. crushers installed on construction sites,
- 3) Government quarries, and
- 4) imports from the PRC in the form of both aggregates and natural sands.

The annual supplies of aggregates over the period 1975 to 1987, and the respective sources, are shown in figure 2.

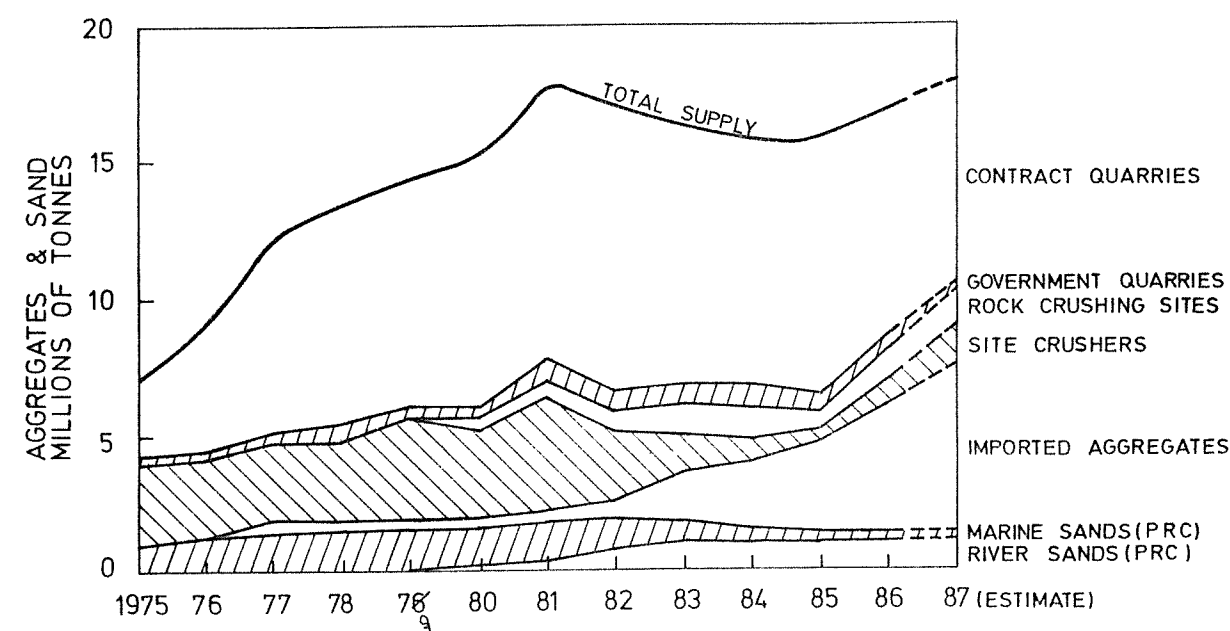


Figure 2 - Supply of Aggregates and Sand 1975-1987

The relative importance of the four aggregate sources has changed considerably during the last 12 years and their respective percentage market shares in the years 1975, 1982 and 1987 are shown on the pie charts in figure 3.

Of the more than 7 million tonnes of aggregates supplied in 1975, 84% of the market was equally divided between the site crushers, which were then permitted to sell their output off-site from private and PWD construction projects, and the contract quarries. Marine dredged sands were then in demand for use in concrete and constituted 13% of the total supply of aggregates. The two Government operated quarries made up the remaining 3% of supply.

In 1981 Government, upholding its stated policy that the contract quarries should provide the Territory's main sources for the supply of crushed rock, introduced strict controls on site crushers. By restricting the sale of crushed rock off-site from construction projects, Government not only provided the necessary incentive to the contract quarry operators to fund substantial investments in new plant and long term quarry development but also phased out the supply of processed stone where quality control was often neglected. Privately run rock crushing sites under Government contracts were established in order to receive surplus rock from nearby construction sites for processing into quality aggregates.

By 1982 the Territory's annual supply of aggregates had grown to over 17 million tonnes. Around 65% of the market was supplied by the contract quarries and the rock crushing sites. Site crushers and the importers of natural sands from PRC (in equal proportions of marine sand and river sand) were left with market shares of 15% and 11% respectively. It became evident in the early 1980s that the demand for aggregates was running ahead of the locally available supply and additional supplies of aggregates were obtained from Macau and the PRC. By 1982 the aggregate importers had gained 4% of the market.

Although the quantity of aggregates obtained from the contract quarries and rock crushing sites remained largely static during the 1980s, their percentage share of the rising market declined. The site crushers were largely phased out, their market share consequently decreasing. A number of Hong Kong PRC joint ventures were formed to operate the new quarries in the Shenzhen and Zuhai SEZ's and the market share held by aggregate importers rose steadily during the 1980s.

Of the 18 million tonnes of aggregates, which will be supplied to Hong Kong in 1987, it is forecast that the combined market share held by the contract quarries and the rock crushing sites will fall to 47% whereas imports will supply 40% of the market. Natural sand, now almost exclusively river sand, will retain a 7% market share.

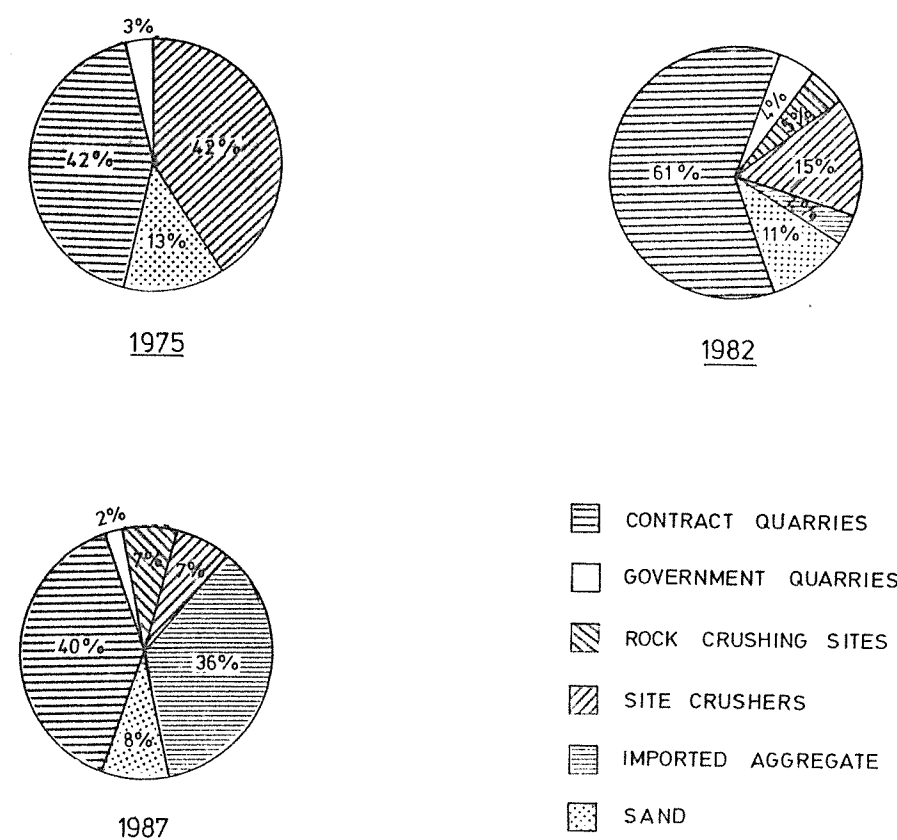


Figure 3 - Aggregates and Sand Production

Quarries in Hong Kong and the PRC

The vast majority of aggregates in the form of crushed granite are sourced from quarries, either the contract quarries in Hong Kong or the newly established quarries in the Shenzhen and Zhuhai SEZs. In Hong Kong, there are currently six contract quarries, one government quarry and two rock crushing sites. Only one site crusher operator, associated with the Eastern Harbour Crossing project and located at the site of the former Cha Kwo Ling contract quarry, has a concession to sell aggregates off-site. The locations of Hong Kong's quarrying operations are shown in figure 4.

Excluding the rock crushing sites and Diamond Hill Area B (a recently awarded site formation contract, including the right to quarry stone, the location of which adjoins the now closed Diamond Hill Government quarry), no green sites specifically for quarrying have been allocated in Hong Kong since 1965 when a quarry at Shek O was first established. All other quarries are located at sites which were previously worked either as an earlier contract quarry or as a permit quarry, some dating back over 30 years.

Due to the shortage of suitable new quarry sites in Hong Kong, established quarry operators, and new operators seeking to enter the Hong Kong aggregate market, have formed joint ventures with PRC companies and established quarries in the PRC. Around 16 quarries now operate in the PRC with the prime purpose of supplying aggregates to Hong Kong. A further three quarries are believed to be under development. During the early 1980s, a quarry in Macau also shipped a substantial proportion of its output to Hong Kong. The known locations of quarries currently exporting aggregates to Hong Kong are shown in figure 5. There are no restrictions or royalties payable on the importation of processed stone into Hong Kong.

Crushed Fine Aggregates and Natural Sands

The most accessible sources of fine aggregate in Hong Kong are its coastal sandy beaches. However, the over exploitation of the Territory's beaches in the 1930s led to the enactment of the Sand Ordinance in 1935 which was intended to regulate the importation and the removal of natural sand. The supply of sand in Hong Kong thus came under direct Government control and the Sand Monopoly was created in the late 1930s.

Under the Sand Monopoly, sands were dredged from local coastal waters under Government contracts for sale through Government sand depots. Marine sands were accepted as suitable for use in the production of concrete, mortars and plasters up until the late 1970s. Although easily accessible reserves of marine sands in local waters were largely depleted by the early 1960s, the Government contractor was able to secure the agreement of the PRC authorities to obtain additional quantities of marine sand from beaches in Mirs Bay. Government purchased the entire production of the dredging operations by contract and then retailed the sand to the construction industry.

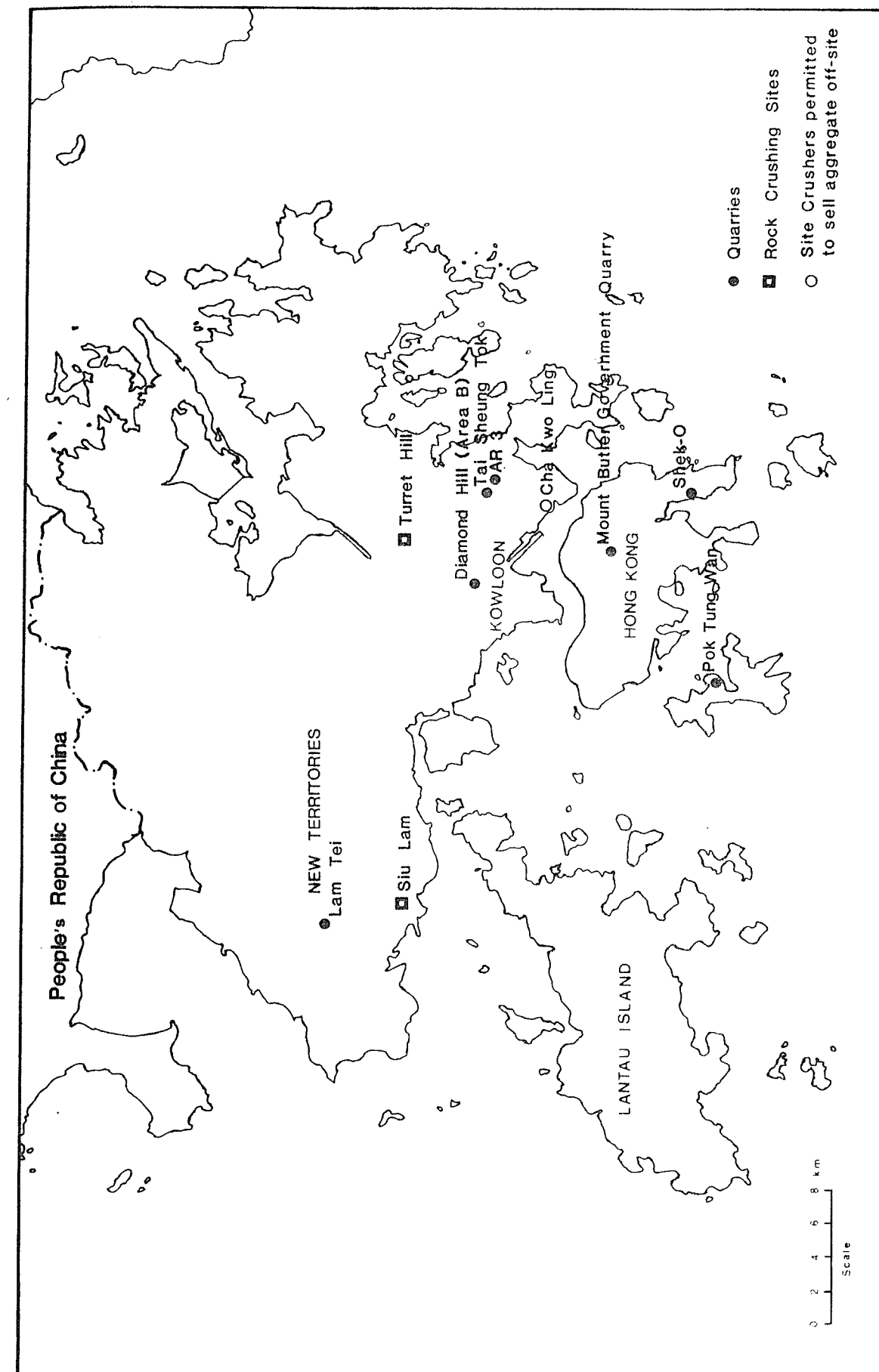


Figure 4 - Quarries and Rock Crushing Sites - 1987

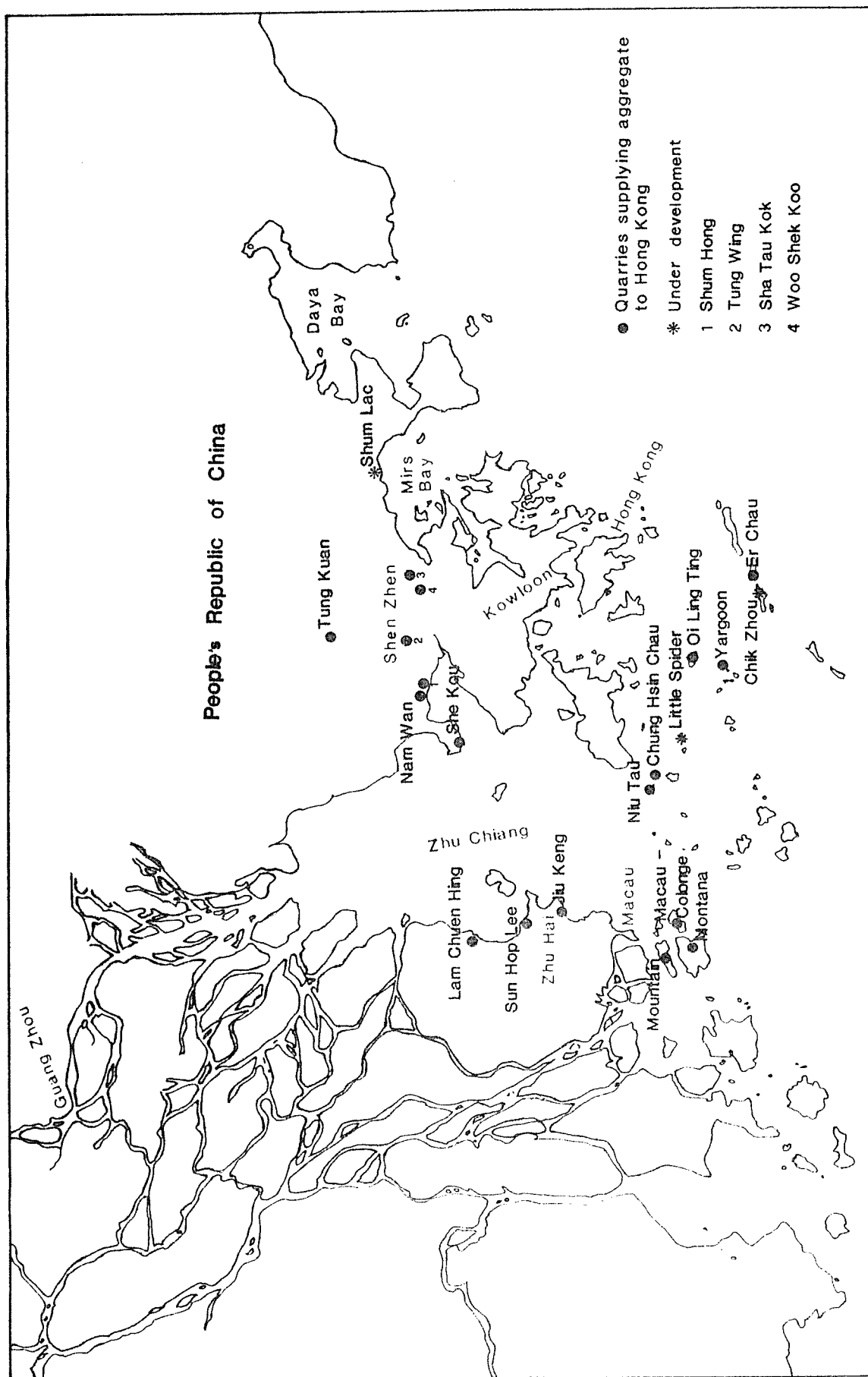


Figure 5 - Quarries in P.R.C. Supplying Hong Kong - December 1987

To supplement the supply of fine aggregates Government conducted trials with various alternative sand manufacturing processes with varying degrees of success :

- i) the washing of decomposed granite (1967);
- ii) the Waterworks Office experimented with a sand classifier to produce filter media (1969);
- iii) the Government quarry installed additional crushing plant to increase crushed rock fines production (1974); and
- (iv) a contract for the supply of manufactured sand at Shek O was awarded (1976).

The trials with washing decomposed granite and the sand classifier were not successful, the sand could not be produced economically and its quality was inconsistent. On the basis of the limited success of the manufactured sand supply contract, a similar contract at Lam Tei was awarded in 1978. Because of its fine grading and the risk of shell and residual salt content, marine sands were considered as unsuitable for use in structural concrete in the late 1970s, thereby compounding the problems already encountered by the concrete industry in sourcing sufficient quantities of fine aggregates. However, by the end of the decade, the contract quarries and the site crushers had considerably increased their production of crushed rock fines to the point where 35% of a typical quarry's output was fine aggregate. Consequently, Government's intervention in the sand supply market was no longer necessary and the Sand Monopoly was abandoned with effect from 1 July 1981. The two contracts for the supply of manufactured sand were also terminated.

Significant quantities of a natural sand dredged from rivers in the PRC were also marketed in Hong Kong from 1980 onwards. Today, river sand has largely supplanted marine sand as the construction industry's most preferred natural sand. However, river sand has yet to make a significant impact on the concrete industry as a substitute for crushed rock fines. Despite concrete manufacturing accounting for almost 30% of river sand imported into Hong Kong, only 7% of the Territories total output of concrete contains natural sand as a fine aggregate - the remaining 93% of concrete produced comprises of crushed rock aggregates only.

Acknowledgement

This paper is published by the permission of the Director of Civil Engineering Services of the Hong Kong Government.

The nature and occurrence
of sand deposits in Hong Kong waters

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SUMMARY A major offshore reconnaissance geophysics survey has recently been carried out by the Geotechnical Control Office as part of an investigation to locate deposits of granular material suitable for use as reclamation fill. Information provided by this survey has allowed modification and extension of interpretations developed during the systematic 1:20 000 scale offshore geological mapping programme. Sand bodies occur in two major offshore lithostratigraphic units, the marine deposits and the alluvium. The older sand bodies were deposited as river channel sands in the Pleistocene period. During the subsequent Holocene marine transgression sand bodies formed as either basal, transgressive sand sheets or as sand banks in areas of tidal streaming. Present day sea bed sands exist in areas of higher current activity, such as narrows and channels, where scour may have exposed and eroded the underlying alluvium and the strong currents redistributed it close to channel thresholds. Sands also occur as beaches and nearshore deposits as well as in modern river channels and their offshore continuation.

Introduction

In the past, sand has been obtained predominantly from onshore sources in Hong Kong, either by crushing fresh granite or washing weathered granite. Offshore sand has mainly been won from surface deposits, formerly from beaches and more recently from the floors of tidal channels and sea bed residual sands (Guildford, this volume). Offshore geological investigations by the Geological Survey Section, Geotechnical Control Office, as part of the 1:20 000 scale Territory-wide remapping programme have demonstrated that large bodies of granular material occur offshore in other geological conditions and locations. A recent offshore reconnaissance geophysics survey (Figure 1) has provided confirmation of the earlier palaeoenvironmental interpretations (Shaw & Arthurton, 1988) and has extended these geological investigations into previously unsurveyed waters providing a more complete understanding of the Quaternary geological history of the offshore zone. A knowledge of the genesis of these deposits is a valuable predictive tool for planning further reconnaissance surveys (Arthurton, 1987).

The offshore Quaternary geology of Hong Kong

The offshore geological survey was carried out using several main sources of information (Shaw, 1987). Firstly, existing site investigation borehole records were assembled and plotted. These logs provided the most extensive collection of information on the characteristics of the offshore sediments. Their main disadvantages are twofold; namely that they are, by their nature, concentrated in areas of engineering activity, which are predominantly coastal locations, and the standard of logging is very variable, in that logs usually provide generic assignment of deposits rather than detailed descriptions of the materials. In addition fourteen continuously sampled boreholes were specially commissioned from both public and private projects in Hong Kong waters. These samples allowed very detailed geological logs to be compiled and provided stratigraphically controlled samples for pollen analysis and radiocarbon dating (Shaw, 1985; Shaw *et al.*, 1986;

Strange and Shaw, 1986). Finally boomer traces produced for a variety of offshore engineering projects were examined and geologically reassessed to determine the distributions of the stratigraphic units previously identified.

These studies have revealed that, in the areas examined, the offshore deposits comprise two main lithostratigraphic units; marine deposits overlying predominantly alluvial deposits. These units have been given formational status and named the Hang Hau Formation and Chek Lap Kok Formation respectively. They are named after type-sections described in continuously sampled boreholes at Junk Bay (Hang Hau) and Chek Lap Kok (Strange and Shaw, 1986). This sequence overlies a mantle of weathered bedrock, of variable thickness, that rests ultimately on unweathered bedrock.

It is widely recognised that world sea-level fell during each of the four major glaciations of the Pleistocene period, that is between 2 million to 10 000 years ago. Snowfalls in the polar regions accumulated in the expanding ice caps, withdrawing water from the normal hydrological cycle of evaporation and precipitation. During the final glaciation world sea-level fell to about 120 m below its present level. The 120 m bathymetric contour accords approximately with the edge of the South China continental shelf which lies about 130 km to the south of Hong Kong. During this period the existing river pattern would have extended southwards to the southern coastline. Evidence of channels incised in the surface of the continental shelf can be seen on small-scale maps. The East River of the Pearl River system would have extended its distributary pattern southwards and eastwards between the islands of Hong Kong, eroding channels and depositing the alluvium of the Chek Lap Kok Formation.

Seismic records indicate that an irregular landscape existed prior to the deposition of the alluvium. A weathered profile with corestones can be identified, but the age of the weathering is unknown except that it is older than the lowest alluvial deposits. A radiocarbon date from wood fragments at the base of the type-section in the Chek Lap Kok borehole gave a date of greater than 40 000 years Before Present (BP) (Strange and Shaw, 1986), the limit of the radiocarbon dating technique. Preliminary contouring of the bedrock surface identified on seismic records of the reconnaissance survey indicate that a buried valley runs from west to east along the line of Urmston Road then north to south from Ma Wan to Green Island. The valley floor falls from about -40 mPD in the Urmston Road area to -60 mPD southwest of Tsing Yi to -80 mPD at the southern end of the East Lamma Channel. Seismic records from the West Lamma Channel are affected by the accumulation of biogenic gas at a level near the base of the muddy marine deposits. This gas is opaque to seismic pulses and produces a phenomenon known as gas blanking (Plate 5).

Deglaciation commenced about 10 000 years BP, at the beginning of the Holocene period. As a consequence world sea-level began to rise, reaching a level slightly above its present level by about 6 000 years BP. This rising sea-level inundated the alluvial plains of the continental shelf and Hong Kong waters; marking the beginning of the deposition of the marine Hang Hau Formation deposits. The surface of the alluvium in the western part of Victoria Harbour has been shown to be eroded by a dendritic pattern of channels that were probably tributary to a master stream occupying the valley running down the East Lamma Channel (Figure 28 in Strange & Shaw, 1986). Similar channels have been identified in several areas during the recent reconnaissance survey (Plates 3 and 4). Preliminary contouring of the surface of the alluvium indicates that the master valley followed the same course as the earlier bedrock valley, the latter having been infilled by between 10 to 20 metres of alluvium. Thus the surface of the alluvium falls from about -30 mPD in the Urmston Road area to -40 mPD

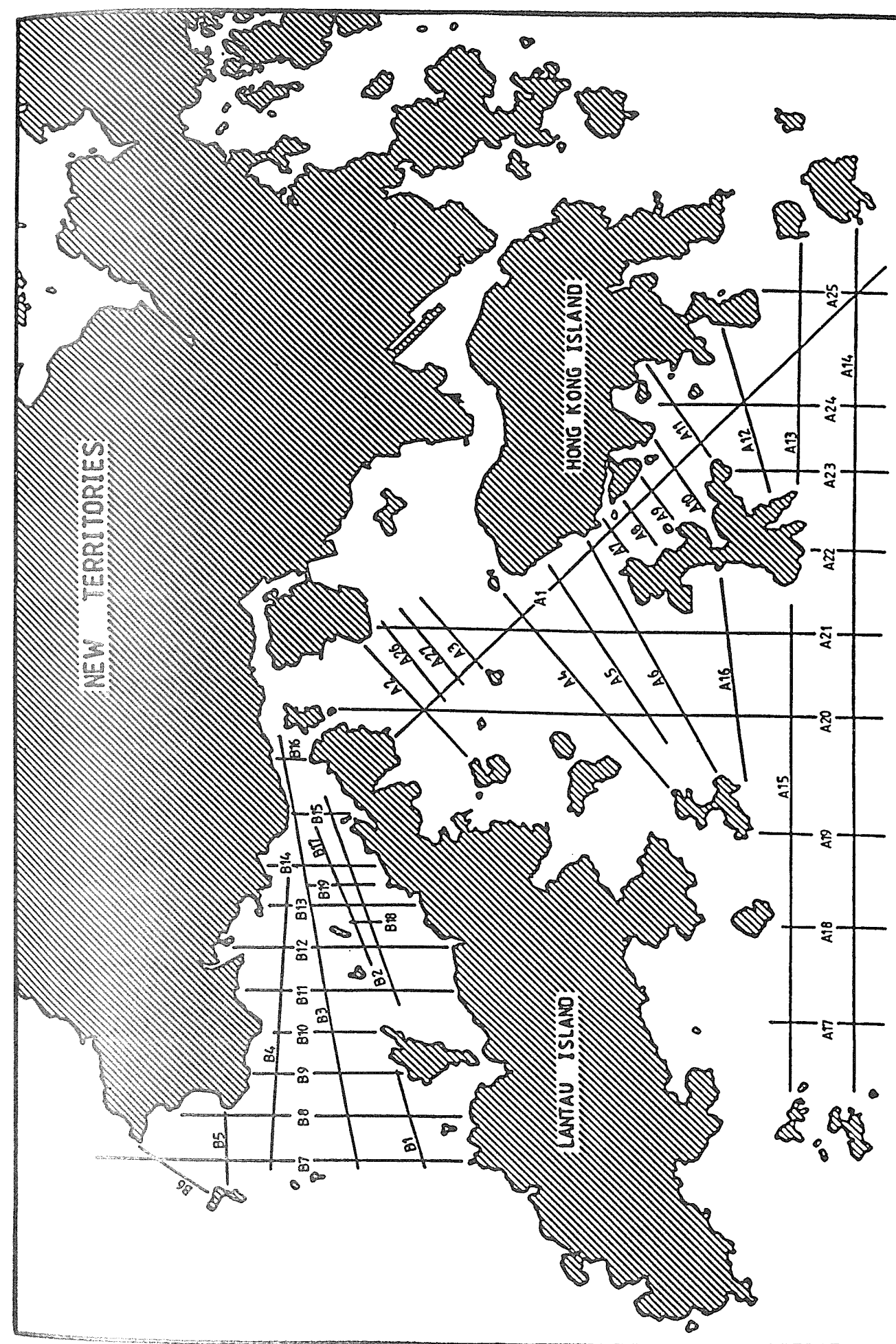


Figure 1 GCO Marine Resources Survey : Stage I Reconnaissance Geophysics Survey Lines. Areas A & B

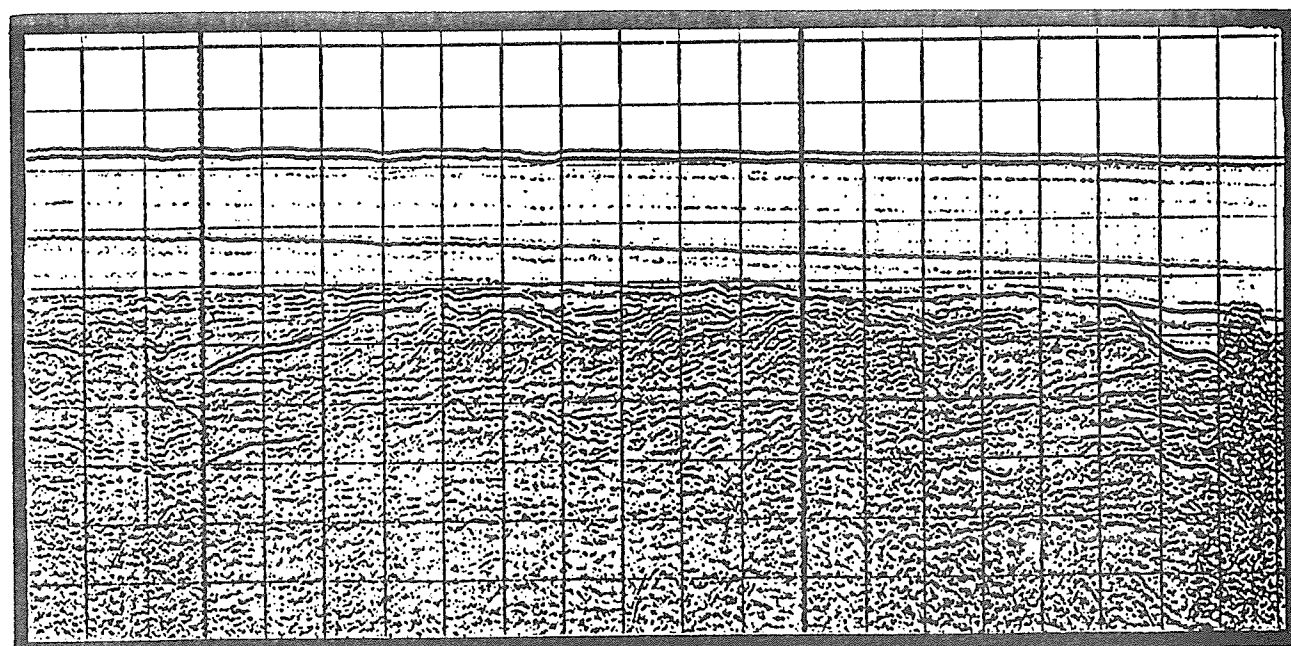


Plate 1 Steeply Inclined Seismic Reflectors of a Suspected Sand Body at the Top of the Chek Lap Kok Formation : Line B8, Northwest of Chek Lap Kok Island

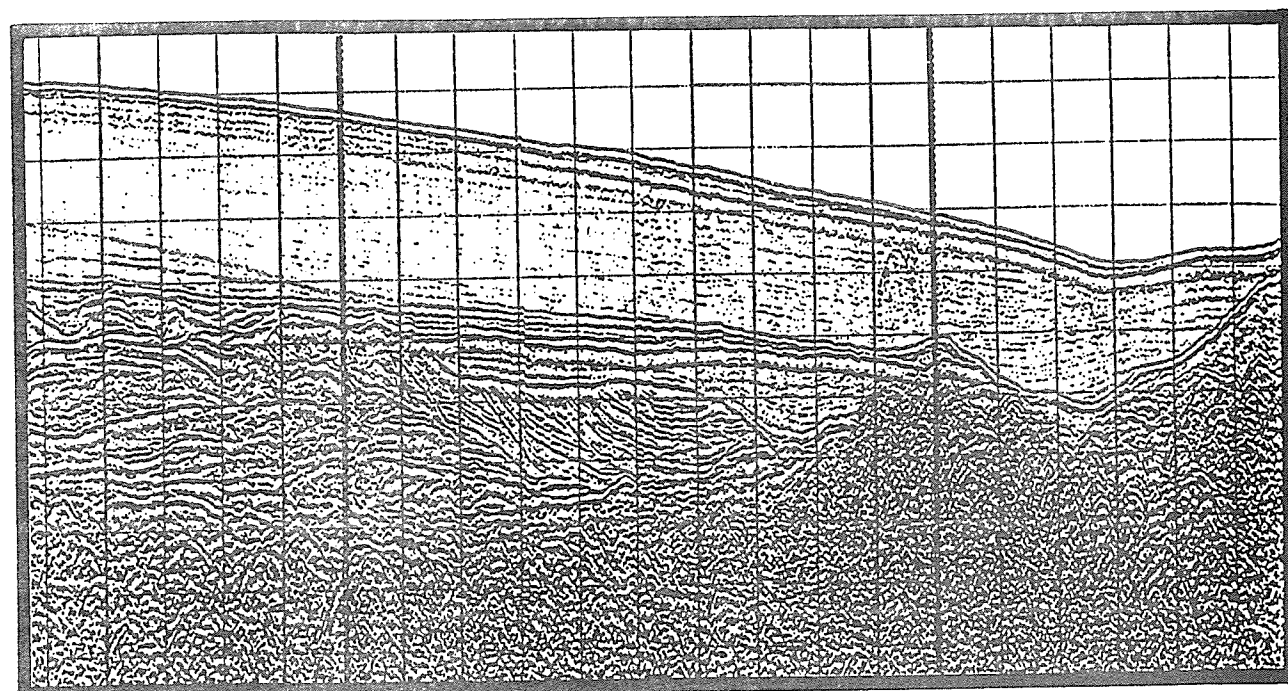


Plate 2 Steeply Inclined Seismic Reflectors of a Suspected Sand Body Within the Chek Lap Kok Formation : Line A6, Northwest of Lamma Island

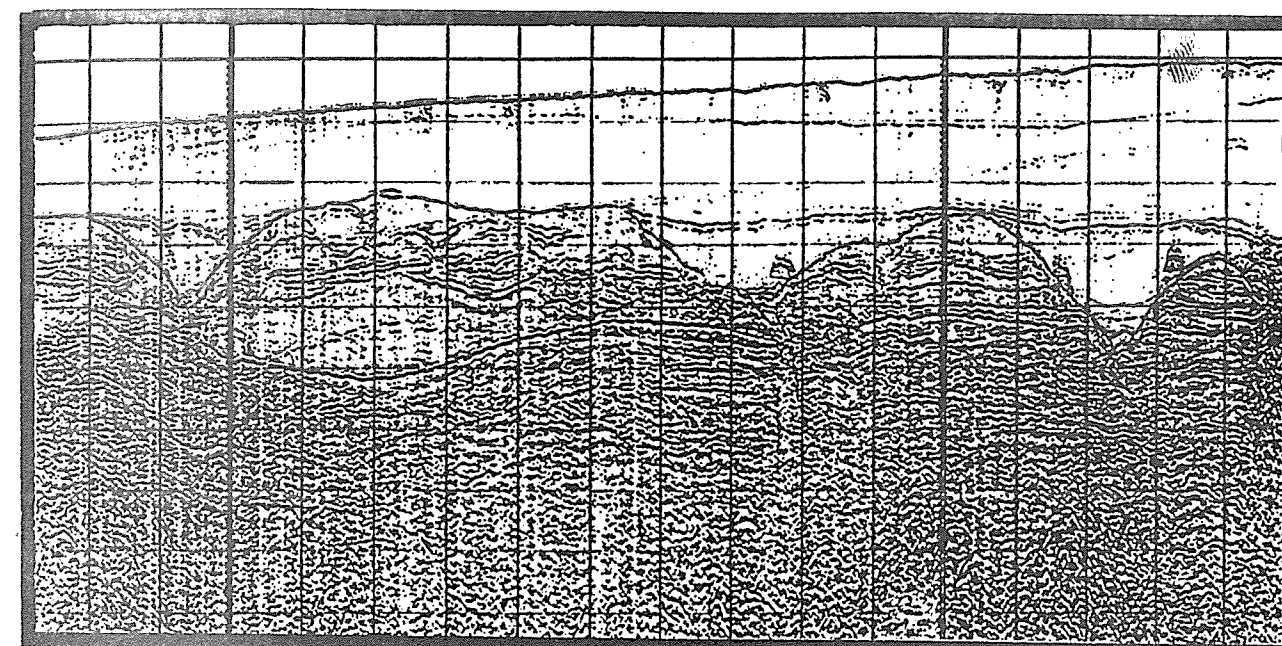


Plate 3 Gullied Surface of the Chek Lap Formation Alluvium : Line B13, South of Pearl Island

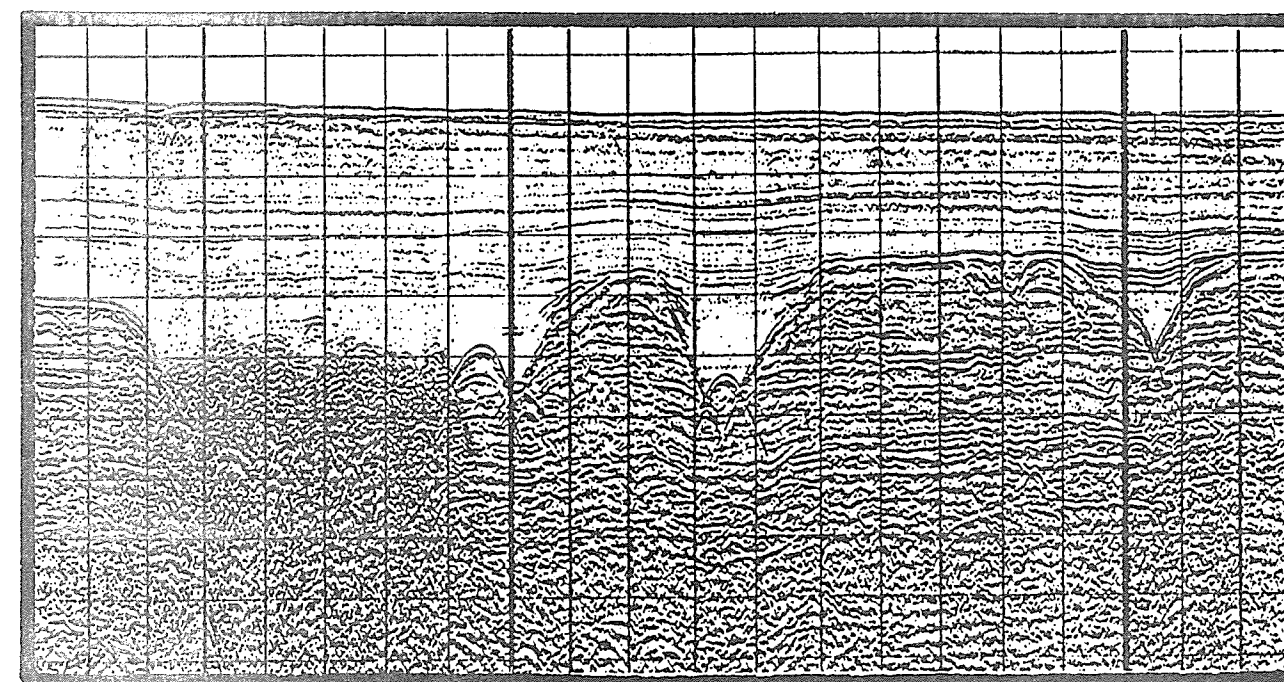


Plate 4 Gullied Surface of the Chek Lap Kok Formation Alluvium : Line A2, Southeast of Penny's Bay, Lantau Island

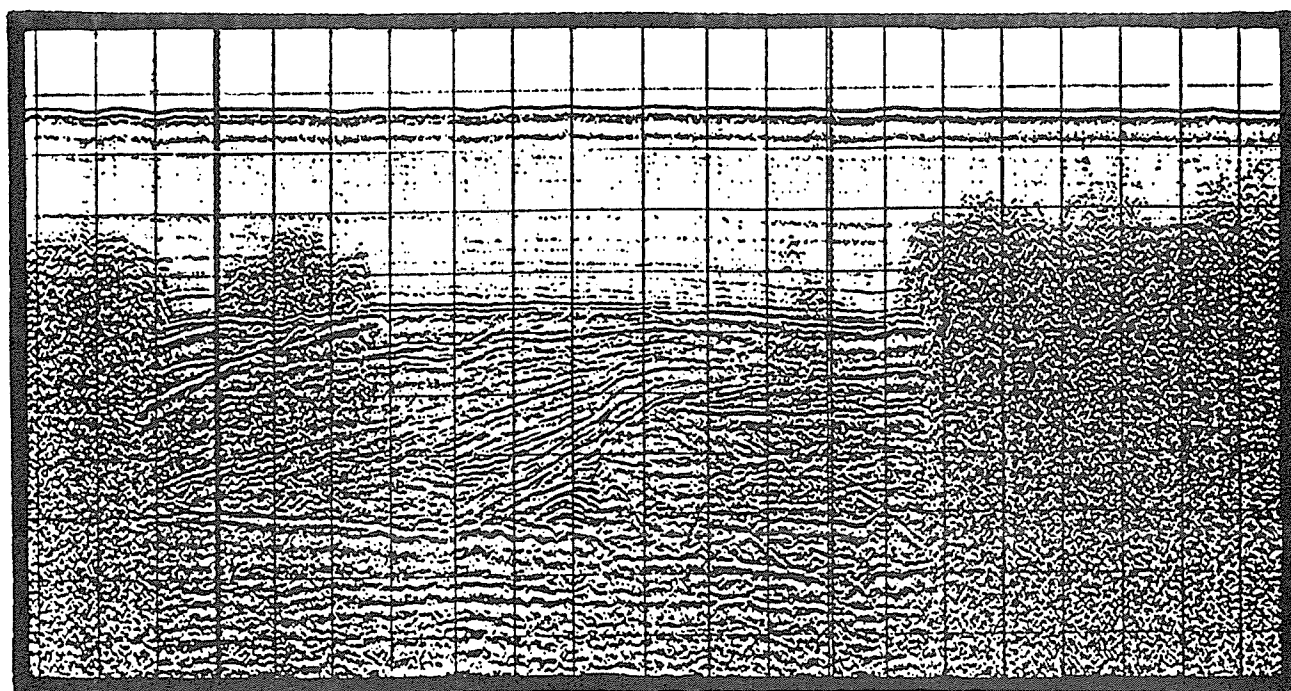


Plate 5 Steeply Inclined Seismic Reflectors of a Suspected Sand Body Obscured Laterally by Gas Blanking : Line A6, West Lamma Channel

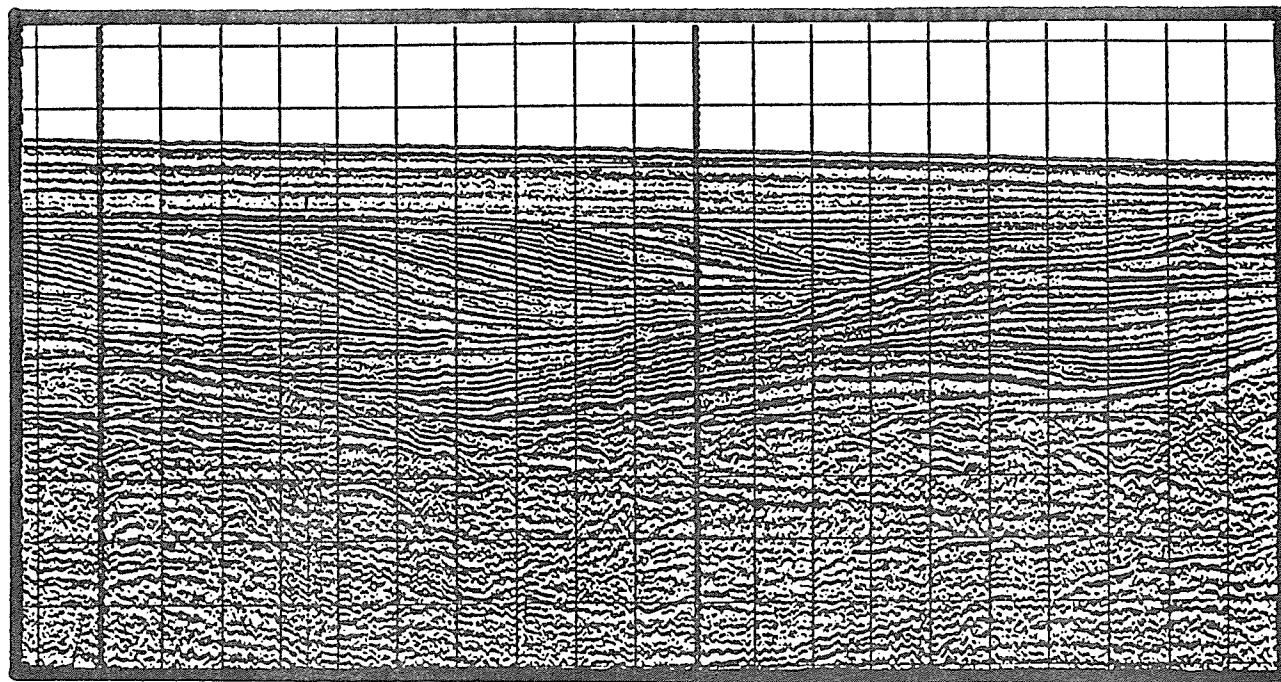


Plate 6 Steeply Inclined Seismic Reflectors of a Suspected Sandy Basal Marine Unit : Line A13, South of the Stanley Peninsula

southwest of Tsing Yi to -60 mPD at the southern end of the East Lamma Channel.

As the rising sea-level reached about -30 mPD most of Hong Kong's southern waters would have been covered by the sea with a long inlet penetrating the East Lamma Channel up to the Kap Shui Mun Channel and possibly into Urmston Road. During this period a strong tidal current would have prevailed through this zone, probably causing erosion of the underlying alluvium and almost certainly strong enough to transport and redistribute a coarse sand bedload. Radiocarbon dating of shell remains from a level of -19.50 to -19.88 mPD in a continuously sampled borehole from Junk Bay yielded a date of $8\,080 \pm 130$ years BP (Strange & Shaw, 1986) indicating that the rising sea-level had reached this level by that date. As the water deepened the tidal currents would have slackened and mud deposition began over large areas.

Modes of offshore sand occurrence

Offshore sand deposits can be attributed to several major modes of formation (Table 1), although there is inevitably some overlap between the different types of deposit. The oldest type is that of the Pleistocene river channel sands, deposited on the bed of meandering or braided river channels that extended across the area during the period of low sea-level. In detail there are distinctive differences between the deposits of these two major river channel patterns, but in general cross-bedded sands form on the channel beds and finer-grained silt and clay deposits accumulate on the floodplain or inter-channel flats and islands. Channel sand deposits can be recognised on seismic records by their generally lenticular form and crossbedded internal structure (Plates 1 and 2), appearing as a series of steeply inclined, usually dense, sub-parallel reflectors that contrast markedly with the irregular, commonly chaotic pattern of the adjacent silty and clayey deposits. Studies of these Pleistocene sediments in continuously sampled boreholes (Shaw, 1985, 1987) have shown that the silts and clays are usually strongly mottled, indicating weathering in a sub-aerial environment. Analyses of pollen grains extracted from the sediments have confirmed a terrestrial origin for most of the sediments (Shaw *et al.*, 1986; Strange and Shaw, 1986).

During the initial stages of the Holocene marine transgression the shallow tidal waters would have reworked the underlying alluvial deposits to varying degrees, depending primarily upon the energy of the currents. The effect would have been to wash and winnow the finer-grained materials, carrying them away in suspension, leaving a lag deposit consisting predominantly of sand. This sand, of variable thickness, constitutes a basal transgressive sand deposit. Redistribution by the currents commonly imparts a distinctive cross-bedded internal structure. This phenomenon appears to be well displayed on the seismic records from south of the Stanley Peninsula (Plate 6), although borehole information is still required to determine the lithology of these sediments. In the area of constricted flow to the south and west of the Kap Shui Mun Channel similar sandbanks occur. The southern sandbank is largely covered by Holocene marine muds, but is exposed at the sea bed on the floor of the tidal channel (Whiteside, this volume). The western sandbank is situated to the south of the present tidal channel, against the north Lantau shore (Plate 7). This feature is believed to be moribund (Evans, this volume), formed by tidal currents prevailing during the early stages of the transgression; it is now no longer developing. The northern margin of the sandbank slopes down on to a rock-floored channel, scoured clean by contemporary currents. Its southern margin is partly buried by marine mud deposits extending out from the northern shore of Lantau Island and overlapping up the steeper face (Plate 7). Sandwaves appear on the seismic records as crenulations on the upper surface of the bank. Westwards the crest of the bank

decreases in elevation and widespread mud deposits have accumulated. South of Pearl Island, Tuen Mun, the lateral representative of the northeast Lantau sandbank is a basal sand sheet (Plate 8), similar to that described off the Stanley Peninsula. On the seismic records the overlying Holocene marine muds can be seen to downlap into the modern bathymetric channel of Urmston Road, where they are incised by a later erosional channel lined by an inset sequence of channel deposits. Neither the age nor the circumstances under which this hiatus occurred are yet known, but a similar break in sedimentation has been recorded in the East Lamma Channel (Plate 52 in Strange and Shaw, 1986).

As the transgression continued the deepening waters would have ultimately lost much of their turbulent energy, and conditions prevailed that favoured the widespread deposition of suspended mud. Tidal currents, driven by the diurnal tidal rises and falls, are concentrated along particular well-defined paths through Hong Kong waters. These currents, either as a result of erosion or by preventing deposition, have formed or maintained channels at certain locations, especially where flow is constricted as at Lei Yue Mun and Kap Shui Mun (Arthurton, 1985). These channels are incised in to either Chek Lap Kok Formation or bedrock (Plate 54 in Strange and Shaw, 1986) and commonly they have a thin veneer or bank of sand on their floors and walls. Away from the channels, where the strong currents begin to dissipate, sheets of sand can be found at the sea bed. These residual sands are believed to comprise both sands eroded from bedrock and Chek Lap Kok Formation outcrops in the channels and the winnowed remains of underlying deposits. Sand waves, large, migratory bed forms with regular but sinuous crestlines and irregular spacing, may form on the surface of these sands. Controlling factors on the formation of sand waves include a grain size larger than 0.25 mm, water depth and a current velocity of between about 30 to 40 cm/sec (Blatt *et al.*, 1980). Well developed sand waves can be clearly distinguished on side scan sonar records, for example in Tung O Wan Bay, southeast Lamma Island (Plate 9).

Of extensive occurrence, but legally protected from exploitation, are the coastal sands, forming either the beaches (littoral sands) or near-coastal (sublittoral sands) deposits, which usually floor the coastal bays. They largely consist of materials discharged into the sea by rivers, reworked by wave activity and redistributed by coastal long shore currents. They can be expected to be less extensive or finer grained in areas of low sediment supply or weaker currents, such as the shores of Deep Bay.

Finally, the source of the majority of modern sands are the onshore rivers that transport the eroded detritus of weathered rocks. At their seaward extremities these streams may extend sandy channels or distributaries across muddy intertidal flats, or form deltas or fans if they debouch directly into deep water. Although areally restricted they may form substantial local workable resources, as off Tai Shui Hang in Deep Bay.

Acknowledgments

This paper is published with the permission of the Director of Civil Engineering Services, Hong Kong Government. The author would like to express his appreciation to Bob Addison, Gary Choot, Paul Cheung and Peter Whiteside of the Geotechnical Control Office, and Chris Evans of the British Geological Survey for their advice and assistance.

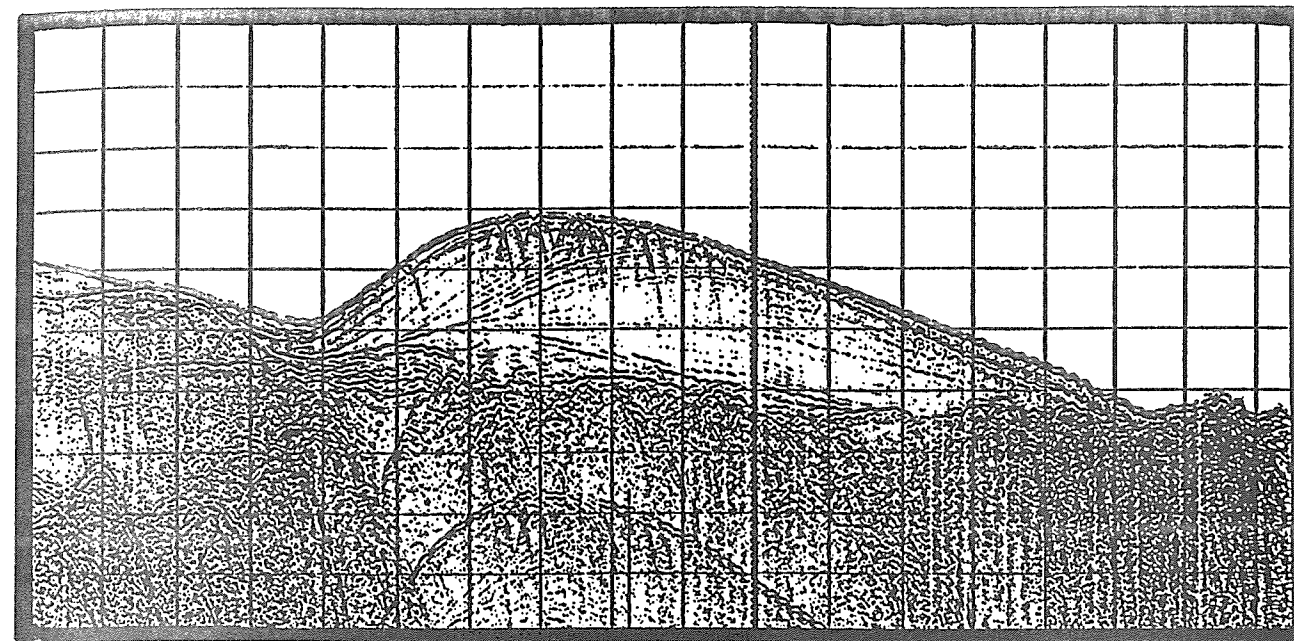


Plate 7 An Asymmetrical Moribund Sandbank Displaying Downlapping Internal Seismic Reflectors, Parabolic Reflectors Near the Crest Due to Dredging Disturbance of the Surface and Onlapping Muds on the Southern (Left-hand) Flanks : Line B15, Northeastern Lantau Island

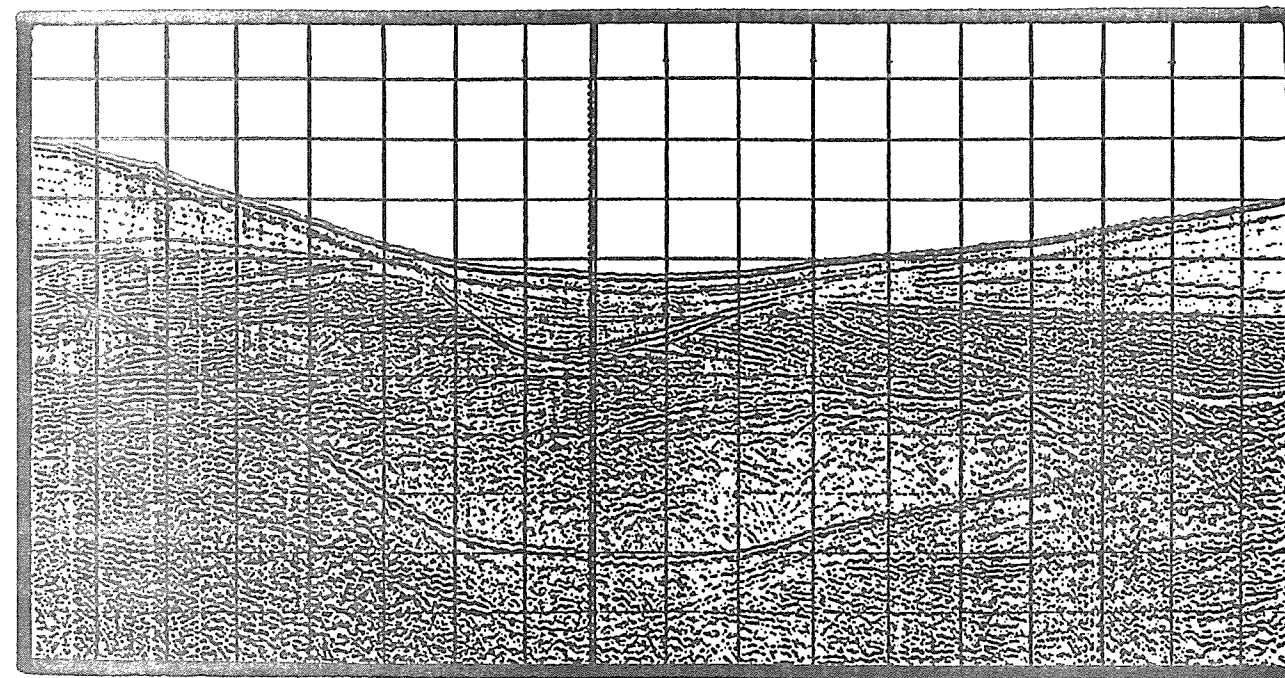


Plate 8 Steeply Inclined Seismic Reflectors of a Sandy Basal Marine Unit Below the Urmston Road Channel : Line B13, South of Pearl Island

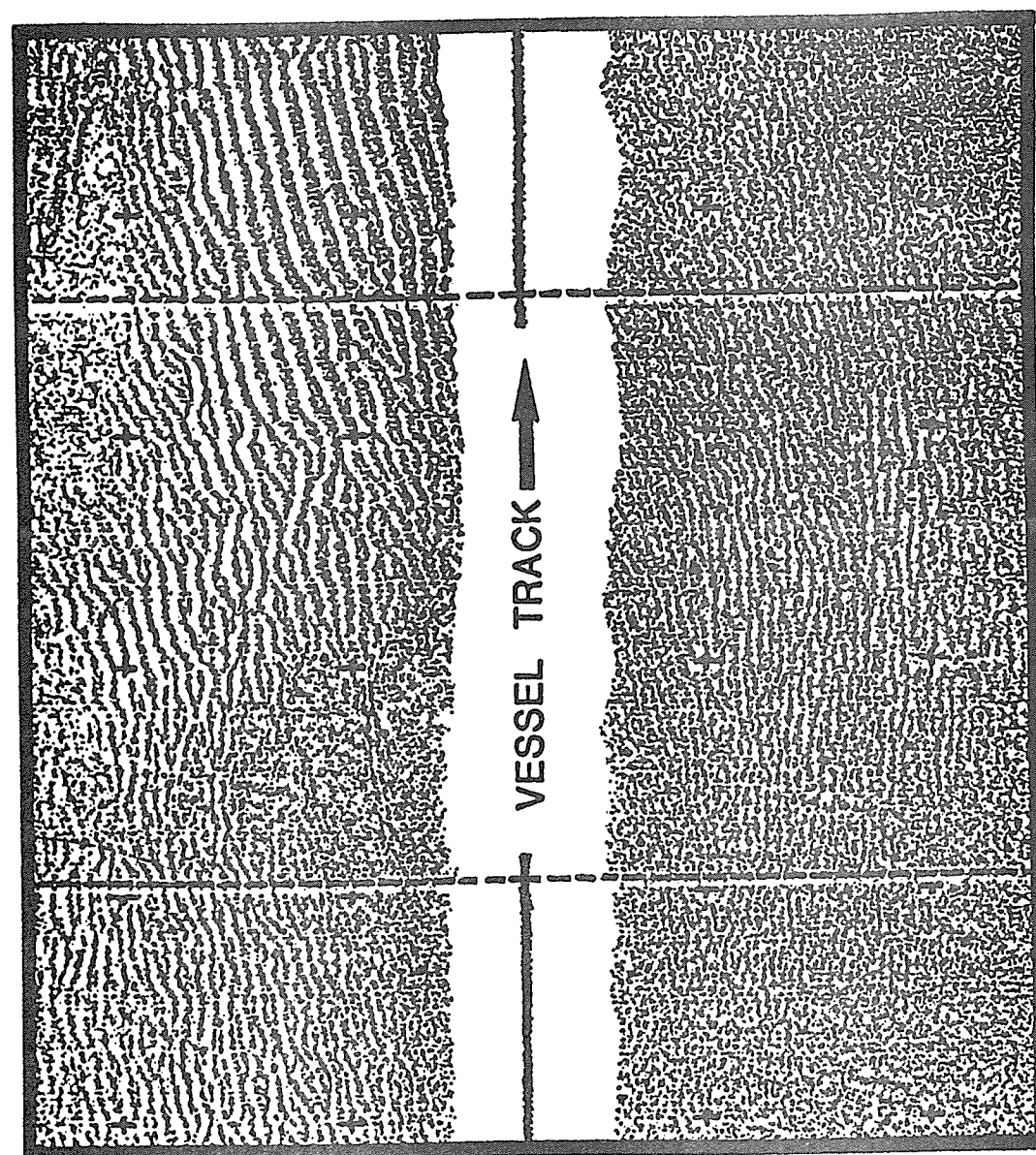
TYPES OF SAND DEPOSIT

HOLOCENE

1. RIVER CHANNEL SANDS
2. LITTORAL AND SUBLITTORAL SANDS
3. SEA BED RESIDUAL SANDS
4. MARINE CHANNEL SANDS
5. BASAL TRANSGRESSIVE SANDS

PLEISTOCENE

6. RIVER CHANNEL SANDS



Side Scan Sonar Trace of Sand Waves in Tung O Wan Bay, Southeast Lamma Island

Plate 9

Table 1 Types of Sand Deposit

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Seismo-stratigraphy of early
Holocene sand banks

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SUMMARY Two small banks are recognized to the north and east of the northeastern tip of Lantau Island, Hong Kong. They were formed during the early Holocene transgression of the area. With the subsequent rise in sea level, they ceased to be active and in part have been covered by younger muddy deposits. The banks form part of a more extensive sand sheet now largely buried beneath these muddy deposits. The sand probably came from the erosion of the Alluvium in the adjacent narrow channels.

Introduction

Sand banks, major bedforms orientated nearly parallel to the local tidal stream, are rare in Hong Kong Territorial waters. Seismic reflection profiling surveys in the area have identified at least two such bodies and this paper attempts to explain their occurrence and present form, in relation to Holocene sedimentation patterns.

Sandbanks-General

Stride et al.(1982) identified two general types of sand banks:-

- a) active banks with an upper surface near to low water level, relief of up to 40m, a maximum slope of the steeper side of up to 6 and a location in areas where the mean spring near surface tidal currents exceeded 60cm/sec.
- b) moribund banks with a similar amplitude to the active banks but with usually gentler slopes, nearer 1, and located where the present tidal currents are less than about 50cm / sec (1 knot).

The median grain size of sand banks is between about 0.1mm to 1.2mm (fine to coarse sand) but the North Sea estuarine sand banks generally lie in the range 0.1-0.2mm. In the Severn Estuary U.K. it has been shown that the grain size of the sand, forming at least the upper part of the banks, is finer than would be expected from the strength of the tidal currents in the area.

Sand banks may be asymmetric in cross-section and the net sediment transport direction and movement of the body, as with ripples, in the direction faced by the steeper side. Banks are orientated at an angle of up to 20 oblique to the peak tidal flow direction.

On the open shelf or in wide estuaries a regular pattern of banks may develop with a wavelength between bodies measured in kilometres. Their

crests may be nearly straight, and many kilometres long, but in tidal estuaries and near coasts they may become S- or V- shaped in plan.

Active sand banks are usually covered by a complex sand wave field, the orientation of which may be used to deduce the net sediment transport around the body. Internally these banks consist of complex cross-cutting sets with occasional, more extensive, lower-angled erosion surfaces. It is recognised that the generation of a bank depends on both the tidal regime and the availability of sand. Without the latter, banks will not form.

On high resolution seismic profiles, banks formed of clean sand rarely display much internal detail because of the lack of acoustic contrast between the lithologies forming the bank and the complexity of the internal cross-cutting units. This characteristic confused, "energy-absorbing" reflector pattern coupled with a surface covered with sand waves provides the clue to the likely lithology of the bank. Where the material forming a bank becomes muddier, usually as a result of formation in an area where current velocities are at the low end for bank formation, then the banks develop stronger and more continuous, undulose, internal reflectors.

The moribund banks have gentler slopes than active banks and the flanks often display more continuous down lapping reflectors. They were formed as active banks during the early Holocene when sea-level was lower than at present. With the rise in sea level the tidal currents in the area decreased and lost the energy to either sustain and enhance, or to erode the bank. With decreasing tidal energy some finer grained material accumulated on the flanks of the bank and the effect of prolonged tidal and wave action was to flatten the top of the body. Kenyon and others (1981) suggest that in the extreme case sand banks may be buried beneath a blanket of mud (see Fig 3e). Moribund banks usually do not have a sand wave cover although they may have a surface of mega-ripples. The best known examples of moribund banks in British waters are the tidal sand ridges in the Celtic Sea and the Sand Hills to the south west of the Dogger Bank (Stride et al. 1982).

Zhujiang (Pearl) River Mouth

The sediment distribution in the Zhujiang (Pearl) River mouth is divisible into three zones; delta front, prodelta and shelf, with Hong Kong Territorial waters situated in the prodelta passing into the shelf section south of Lantau and Lamma Islands (Fig 1). Tidal ridges (equivalent to sand banks) are restricted to the section of the river mouth north-north-west of Hong Kong termed in Lingdingyang between the Humen Gap to the north and Neilingting to the south (Fig 1). The present distribution of the ebb-tidal sand sheet does not extend as far south as Hong Kong waters terminating a short distance south of Neilingting (Fig 1).

The suspended sediment brought down by the river flows down the western side of the estuary and is carried along the western coast of Guangdong Province by the South China Sea littoral current. This movement of sediment is a function of the inflow of continental shelf water through Hong Kong waters and the escape of this same water, mixed in part with the river flow, along the western side of the area. Thus present conditions are not conducive for high volumes of river borne suspended sediment to enter Hong Kong waters.

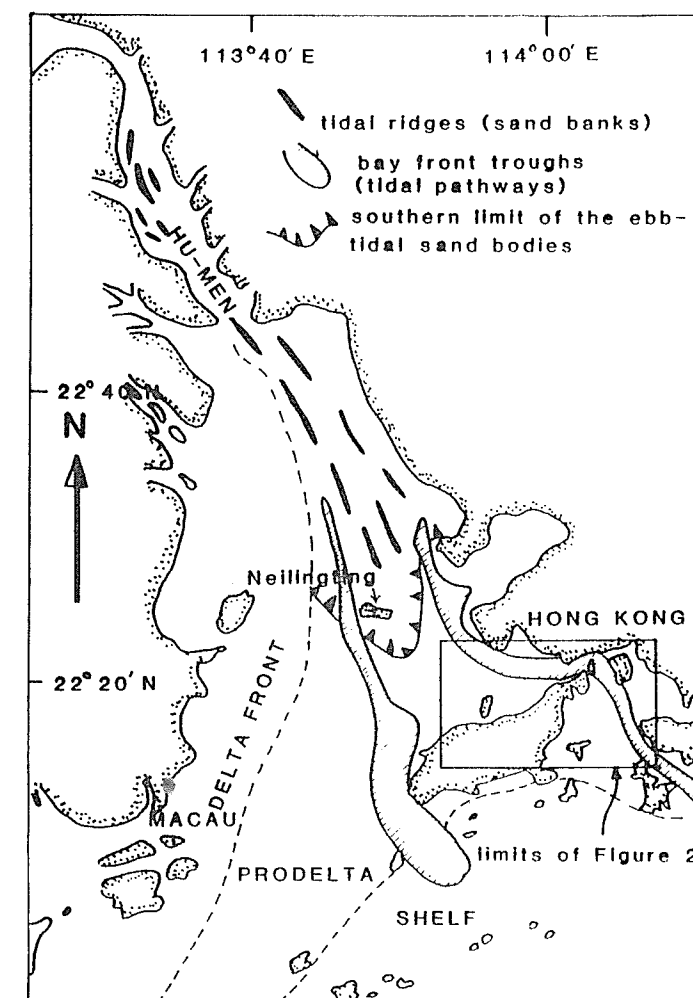


Figure 1. Distribution of sand banks in the Zhujiang (Pearl) River mouth modified from Li and Wang, (1985), Fig 4-47.

Major historical changes in the configuration of the river mouth are known; the Shiziyang Bay approximately between Guangzhou and the Humen Gap was an "immense sea" during the Song Dynasty (960-1279 AD) which has contracted greatly since due sediment infill (Li and Wang, 1985). Thus changes in the Holocene sedimentation pattern in Hong Kong waters must be considered within a regional context.

Holocene stratigraphy in Hong Kong waters

Across much of Hong Kong waters and the Zhujiang River mouth the deeply weathered bedrock is overlain by a sequence (usually termed Alluvium) of multi-coloured, poorly sorted, immature, often dense, sand with discontinuous muddier lenses. The age range of this unit is a matter of debate but it is certainly older, for the greater part, than the Holocene. The top of the Alluvium is usually a well defined disconformity on the seismic profiles, and locally gulleys are incised into the surface. The overlying sequence (Marine Deposits) consists primarily of mud with an extensively developed basal sandier section, the latter being recognised on both seismic profiles and in boreholes.

This succession is identifiable across most of Hong Kong waters; the exception being the region of the narrow deep channels between the islands, such as Lei Yue Mun, between the Po Toi group of islands and Hong Kong Island, East Lamma Channel and Tsing Yi Channel, where the Quaternary sequences are absent and extensive areas of bedrock crop out at sea bed.

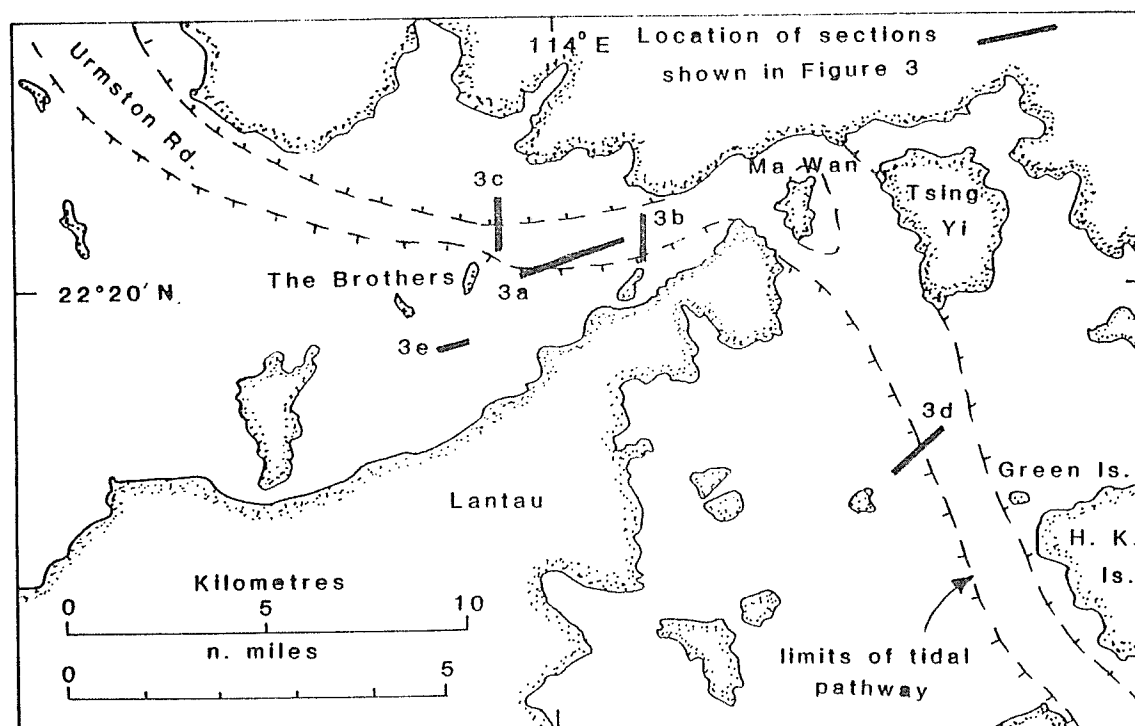


Figure 2 .Location of the seismic profiles displayed in Figure 3.

One such zone examined in detail is the area eastwards from the Brothers to the Tsing Yi Channel and southwards to the East Lamma Channel (Fig 2). This zone is a tidal pathway (or "bay front trough" (Li and Wang, 1985)) for water flowing between the continental shelf south and east of Hong Kong into the upper reaches of the Zhujiang River mouth (Fig 1). This pathway is clearly identifiable on bathymetric charts of the area as a well-defined channel up to about 2km wide, with a floor at least 10m deeper than the adjacent flanks. Where this pathway is most constricted, for a section about 4km long from the north of Lantau to the west of Tsing Yi, bare rock crops out on the floor of the channel, though some Holocene sediment is deposited locally on the flanks.

Alluvium

Seismic profiles across the area (run by Electronic and Geophysical Services Ltd. for the Geotechnical Control Office, Hong Kong Government) show the distribution of the various Quaternary units. A broad low valley with a base level at between -40 to -50m, a maximum depth of -59m, and impersistent sides is traceable in the rockhead levels through the centre of the area. The floor of this feature (the base of the Alluvium) is usually nearly flat with a few deeper, often continuous, gulleys, and its margins may form distinct minor scarps (left hand side of Fig 3a). This same scarp may be recognised at the top of the Alluvium as the unit mantles the underlying relief (Fig 3a). Thus the form of the present tidal pathway is mimicked by a now discontinuous valley in approximately the same position at the top of the Alluvium.

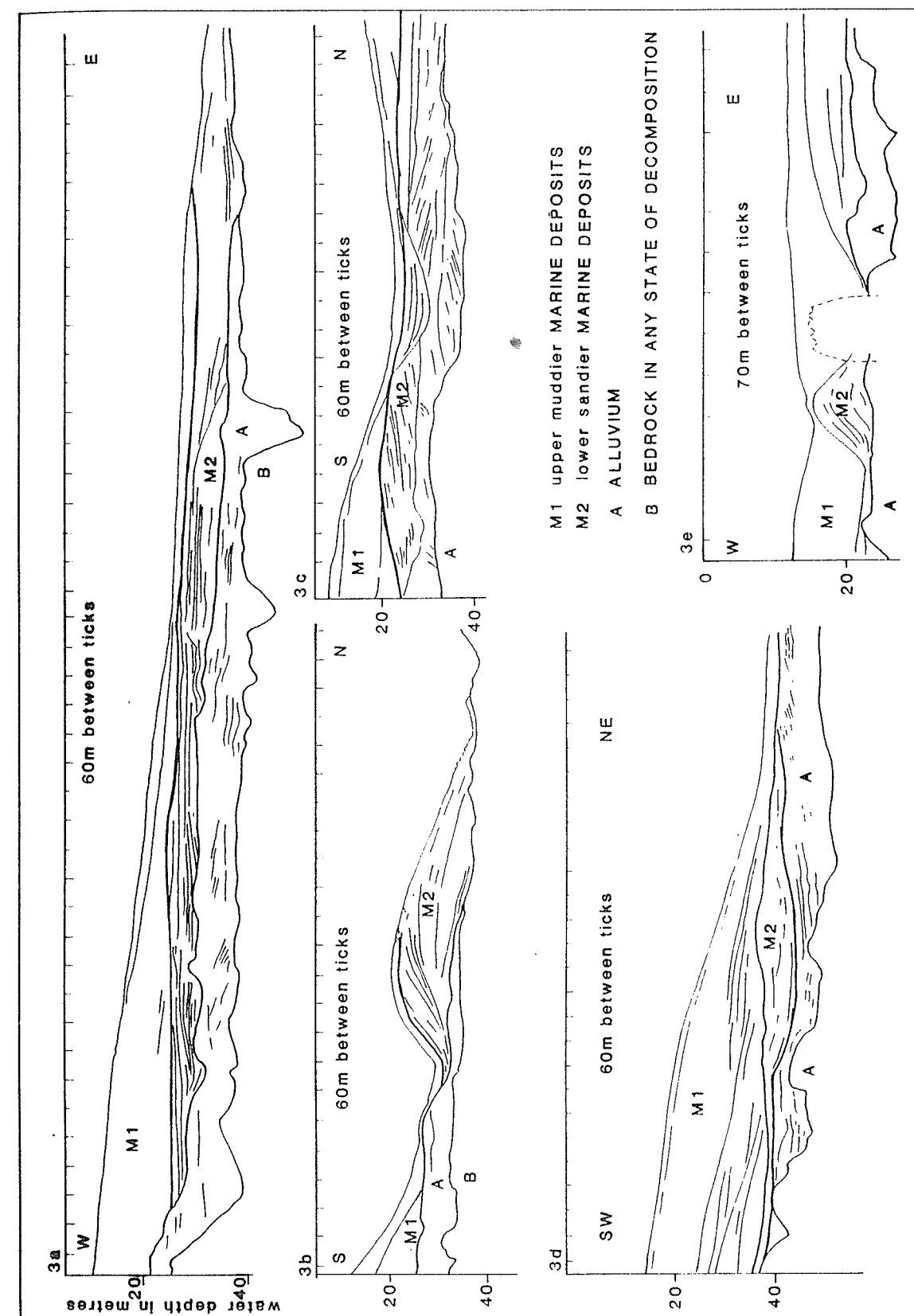


Figure 3. Line drawings taken off boomer seismic profiles run by Electronic and Geophysical Services Ltd. The location of these profiles is shown in Figure 2.

Along the centre of the present channel north of Lantau the basal Alluvium unit thins and terminates towards the east (Fig 3a). This termination of the Alluvium unit towards the narrow sections of the channels is probably due to the enhanced tidal currents within the zone during the early stages of the transgression.

Marine Deposits

The erosion of the Alluvium occurred before deposition of the overlying basal Marine Deposits, therefore sand was available for redeposition during the early part of the transgression. The basal Marine Deposits overlap and extend further east than the Alluvium before they also thin and terminate to the east of the section shown in Fig 3a. The Marine Deposits are divisible into two units; the basal part forms a series of thin (up to 8m) overlapping lenses (probably sandy) westwards at least as far as the southern end of Urmston Road. In Fig 3a this basal sandier section is seen to be confined within the valley formed by the top Alluvium surface. Figure 3c trending north-south across the present tidal pathway shows the basal sands with distinct low angled cross-bedding, cut by a later, now infilled channel. These basal sandier sections crop out at or near sea bed where the overlying muddier section is thin or absent; that is, in the eastern part of the area and in the floor of the tidal pathway. At depth they may extend northwestwards from Urmston Road to pass into the base of the ebb-tidal sand bodies (Fig 1).

Drilling results confirm that the units consist of fine, grey, muddy, shelly sand. These units may have been formed of sands eroded from the narrow channels or brought down by the main river. They were formed during a period when currents through the area prevented the deposition of mud but allowed broad sand sheets to cover the shallows between the islands. During this period, where the current was most intense, no sand was deposited but to the west the sand accumulated firstly as banks and, further away, as the above mentioned sand sheets.

Sand banks

A closer examination of the sand bank shown in Fig 3b shows an asymmetric bank about 600m across and rising some 15m above the ambient sea bed level. Bathymetric data show it to flatten out to the east and west with a crest about 20m below sea level. The surface of the bank is smooth but with minor sandwaves/mega-ripples near the base of the gentler sloping side. The maximum slope in the section is at least 4. The bank near the southern shore rests on Alluvium but this thins to zero northwards (as in Fig 3a) towards the channel centre. The bank contains fine continuous internal reflectors which suggest that the sands forming the body may be muddy.

The basal Marine Deposit sands in Figure 3a and c are overlain by muds which thicken westwards and shorewards away from the tidal pathway to attain an average thickness of about 15m. The muds contain continuous reflectors inclined down from the coastal zones indicating that the muds prograded outwards from the coast to overlap and locally bury earlier deposits. Figure 3e shows the muds burying a small sandier body to the south of The Brothers. A similar situation prevails in Figure 3b (and other profiles across the body) with the Marine Deposit muds encroaching onto the steeper flanks of the sand body.

Tsing Yi Channel

An examination of the southern end of the rock-floored channel between Ma Wan and Tsing Yi shows a similar pattern of sedimentation. There is a low tidal sand bank in the main channel to the south-west of Tsing Yi about 2km long with a top some 13-14m below sea level; a second, lower bank, with its steeper side facing east, may lie to the south-east of it. The former rests on Alluvium and its western flanks are overlapped and overlain by later muddier Marine Deposits. In the tidal pathway to the south-south-east, between Tsing Yi and Green Island, the basal Marine Deposit sandier section crops out in the base of the channel where the muddier younger section is absent. This basal sandier section is less well developed in this area than to the north of Lantau and more work is necessary to confirm its distribution. The Marine Deposits thicken rapidly away from the clearly demarcated tidal pathway, to attain a uniform depth of 10 to 15m (Fig 3d) over extensive areas. Internal reflectors within the unit show it to have prograded to its present position making the channel a depositional not an erosional feature.

Similar features are expected in the channels between the Po Toi Islands and Hong Kong Island where the base of the feature descends to -75m (Admiralty Chart No.3026). No surface or buried banks have been recognised to the south-east of The East Lamma Channel although minor sandy accumulations occur locally on the channel floor.

Discussion

These profiles show that the sandbanks formed early during the deposition of the Marine Deposits and at the time when sand was relatively abundant within the area. The sand probably came from the erosion of the Alluvium Deposits in the inter-island narrows although some may have come down from the Zhujiang River or from the adjacent continental shelf. This sand-dominated deposition must have continued in this area until sea level was at about -20m or shallower, the top of the bank in Figure 3b. The global rising sea level reached this height about 8000 years BP but Liu Yixuan (1985, Figure 2) suggests that in the Pearl River Delta this level was attained about 16,000 years BP. The deepening of the water between the islands probably produced a decrease in the energy of the tidal regime in the area. This may have allowed mud deposition to expand across the area. The seismic profiles show deposition to have extended out from shore and to have buried most of the earlier features. The commencement of mud deposition in the area was probably a diachronous event and dates for the change in one area cannot automatically be applied across the region. In historic times general mud accretion has more or less ceased across the area probably due to a reduction in the suspended sediment entering the area.

Where the early Holocene sand banks persist the tidal velocity is adequate to inhibit mud accumulating but not to actively regenerate the sand bank. The almost complete absence of sand waves from the area has probably more to do with the absence of sand in transit than current velocities. Further away from the high energy corridors between the islands the banks are buried and definitely moribund. The sand bank in Fig 3b has the geometry of an active bank but the almost complete absence of sand waves, the depth of its top and the thin cover of Marine Deposit muds on the southern flanks suggest that it is moribund. Probably the bank is moribund with respect to growth especially as there is so little sand

presently moving in the area. However if the bank is dredged then the tidal regime is adequate to repair any irregularity in the gross form of the body. Dredging an area in the eastern part of the channel to the north of Tsing Yi freed sand and created sea bed irregularities which led to the local development of sand waves. Huthnance (1982) concluded from a mathematical standpoint that the typical evolution time for bank development was measured in centuries. This shows that a dredged bank even with an abundant supply of sand is not likely to reform quickly; where the sand is scarce the time scale is longer.

The sand banks do not appear to be actively forming and the banks which do exist were probably formed during the early part of the Holocene transgression and have only been slightly modified in form since that time.

Acknowledgements

This contribution was prepared using seismic profiles and data provided by the Geotechnical Control Office of the Hong Kong Government. It is published with the permission of the Director of the British Geological Survey.

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Marine dredged sand for use as fine aggregate

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SUMMARY This paper examines the technical merits of using sea dredged sand as a fine aggregate. However, as the bulk of aggregate in Hong Kong is used in the production of concrete this paper deals principally with its use in concrete.

A comparison is made between the properties of locally produced crushed rock fine aggregates and the natural marine and alluvial sands which may be dredged from within Hong Kong waters. Properties of natural river sands and marine sands from the Peoples Republic of China (PRC) are also given for comparative purposes.

The principal characteristics of fine aggregates are described and their influence on the properties of fresh and hardened concrete are explained.

Possible uses for natural sand as a fine aggregate are suggested, and recommendations for future research and development are made.

Whilst it is appreciated that the replacement of crushed rock fine aggregate by natural sands would have economic implications for the local quarrying industry, it is considered that such a review is beyond the scope of this paper.

Introduction

The phenomenal development of Hong Kong's infrastructure in post war years could not have been achieved without a readily available supply of construction materials. Concrete, the world's most commonly used structural material, has played an integral part in this development and the annual consumption of concrete in Hong Kong is at present running at approximately eight million cubic metres. Such has been the extensive use of concrete that Hong Kong has been described, perhaps unkindly, as the proverbial concrete jungle.

Concrete is an heterogeneous material and normally comprises three materials, namely, cement, natural aggregate and water. As the major constituent is natural aggregate, approximately 60 - 75 percent of the volume of the concrete, it is indeed fortunate that Hong Kong has an indigenous and abundant supply of good quality rock from which natural aggregates can be processed.

However, as natural aggregates can have a profound and in some cases a serious deleterious effect on the properties of concrete, care in their selection is of the utmost importance. In view of the inherent risks associated with the use of natural aggregates in concrete it is perhaps worthwhile to reiterate the reasons why aggregates are used.

First, aggregate by comparison with cement is much cheaper. Cement in Hong Kong sells for approximately HK\$400/tonne whereas aggregate sells for about HK\$40 - 50/tonne. As some 60 - 75 percent of the volume of concrete comprises aggregate the replacement of such a large volume of cement paste by aggregate will considerably reduce the unit volume cost of concrete.

Secondly, there are considerable technical advantages in replacing the cement paste by aggregate. It improves the volume stability and durability of concrete, e.g. shrinkage and cracking are reduced, strength is improved, resistance to wear and abrasion are improved; and there are many other advantages which could be listed.

Background

The annual consumption of aggregates in Hong Kong for all purposes is currently running at approximately 18 million tonnes. The local quarrying industry produces some 11 million tonnes, of which approximately 40 percent is crushed rock fines, i.e. 100 percent passing a 10mm sieve, and 7 million tonnes are imported from the PRC. Included in the total for imports from the PRC are 1.3 million tonnes of natural river sand and 90,000 tonnes of marine sand which is understood to have originated from beaches. The river sands are mainly used in concreting whereas the marine (beach) sands, because of their fineness, are predominantly used in mortars and renders. The concrete industry uses 15.3 million tonnes or 85 percent of the total consumption of aggregates in the Territory.

Most aggregate used in Hong Kong is produced by the crushing of granitic rocks. Whilst the use of this rock has served Hong Kong well in the past crushed rock fine aggregates do have specific disadvantages. The relative merits of crushed granitic fines vis-a-vis natural sands as fine aggregate in concrete are summarized as follows :

<u>Crushed granitic fines</u>	<u>Natural sands</u>
<u>Advantages</u>	
(a) established quarrying industry	(a) improved workability of the mix
(b) fines are produced as a concomitant part of processing coarse aggregates	(b) more economic mix design
	(c) good abrasion resistance
<u>Disadvantages</u>	
(a) harder to satisfy grading requirements	(a) possible contaminants (e.g. chlorides)
(b) higher water content	(b) the replacement of crushed rock fines by natural sands may result in an increase in the price of crushed rock coarse aggregate
	(c) may contain reactive minerals

The technical arguments, for and against, are considered in detail in a subsequent paragraph. On balance there is a strong technical argument in favour of using natural sands in concrete. In view of this it is necessary, with the discovery of large, and recoverable, deposits of natural sand within Hong Kong waters, to fully evaluate its potential as an alternative source of fine aggregate.

Specification requirements

There are relatively few specification requirements covering the use of aggregates in concrete and even fewer requirements in respect of fine aggregates. In BS 882:1983: Aggregates from Natural Sources for Concrete, there are only two mandatory requirements for fine aggregates: (a) grading; (b) clay, silt and dust content. There are no mandatory limits for chloride content but limiting values are suggested in the form of an appendix. A notable omission to BS 882 is the requirement for a petrographic examination.

In contrast to British Standards the American Society for Testing Materials (ASTM) standards contain more detailed procedures and provide useful information to those engaged in evaluating unproved sources of new material outside the United Kingdom (UK). In practice the brevity of British Standards could lead to problems particularly where new, and as yet untested, sources of aggregates are being explored.

A detailed petrographic examination of an aggregate, such as ASTM Standard C295-79, Standard Recommended Practice for Petrographic Examination of Aggregates for Concrete, provides useful data and could prevent the use of materials which contain deleterious materials. Alkali-aggregate reaction is a particular case in point, because a petrographic examination is probably the most expedient and safest means of avoiding costly mistakes.

The Hong Kong Government Public Works Specification requirements relating to the use of fine aggregate are in general based on British Standards, and cover three main areas of use, namely; concrete (structural), concrete (carriageway) and bituminous materials. The relevant parts of the specification clauses concerning fine aggregate, mortar, sand and chloride content are attached at Appendix A.

The influence of fine aggregate characteristics on concrete properties

Prior to 1983 BS 882 specified four grading zones for fine aggregate : Zones 1, 2, 3 and 4. The insistence that aggregate must comply with one of these four distinct zones led in some cases to the unnecessary rejection of suitable materials. Furthermore, it was a common misconception amongst some engineers that these four grading zones conferred some form of technical merit. This was not the case. The zones merely represented the grading envelopes of fine aggregates generally available in the UK.

The 1983 version of BS 882 has widened the overall fine aggregate grading limits to permit a greater range of material and has replaced the previous four 'zones' by three overlapping sets of additional grading limits termed coarse, medium and fine. The use of this wider grading envelope in combination with the set of three overlapping grading envelopes

is a radical but welcome change.

Of the specification requirements for fine aggregates it is the grading which has the major influence on the rheology of fresh concrete and the properties of hardened concrete.

The three general principles that apply to the rheology of concrete are that the workability will increase as :

- (a) the maximum size of aggregate increases,
- (b) the aggregate particles become more rounded,
- (c) the overall grading becomes coarser.

It should be understood that these three principles apply to all aggregates irrespective of their size.

The ideal aggregate grading for most situations is that which provides a material having the lowest possible surface area and void content per unit volume. This will ensure that a concrete mix can be designed to achieve the required hardened properties and also achieve the desired workability with minimum water content. Such an aggregate grading should also ensure that undesirable effects in the fresh concrete such as segregation and bleeding are minimized and the required hardened concrete properties in respect of strength, shrinkage and durability are achieved. Of overriding importance is that having once selected a particular aggregate source the grading should remain uniform and constant.

Fine aggregate characteristics

In selecting a fine aggregate it should be understood that certain characteristics of the aggregate will produce particular effects in the fresh and hardened concrete. The nine main characteristics of fine aggregates which greatly influence the properties of concrete are :

- (a) coarseness of the particles
- (b) coarse to fine aggregate proportions
- (c) specific surface
- (d) shape and surface texture
- (e) dust and silt/clay content
- (f) relative density
- (g) deleterious substances
- (h) alkali-aggregate reactivity
- (i) abrasion resistance

These are discussed in more detail below :

Coarseness of the particles - The use of a very coarse sand will result in a harsh unworkable mix unless a high sand and cement content is used. A harsh mix is also susceptible to bleeding and segregation and would almost certainly be difficult, if not impossible, to pump. Conversely, the use of a very fine sand will result in a cohesive and unworkable mix. Such a mix would also require a higher water content, possibly resulting in a lower strength, a low sand content, and care would also be necessary in selecting the aggregate proportions otherwise a gap-graded aggregate may result.

Coarse to fine aggregate proportions - The selection of a particular fine aggregate grading will also affect the coarse to fine aggregate proportions. Research at the Building Research Station in the UK on sand led to the suggested proportions as shown in Table 1. It is clear from this table that the ratio of coarse to fine aggregate should be higher the finer the grading of the fine aggregate.

Table 1 : Suggested Proportions by Weight of Coarse to Fine Aggregate for Sand of Different Zones

Maximum size of coarse aggregate mm	Coarse/fine aggregate ratio for sands of zone :-			
	1	2	3	4
10	1	1.5	2	3
20	1.5	2	3	3.5
40	2	3	3.5	

(DSIR Building Research Station, Principles of Modern Building, London, HMSO, 1959)

Specific surface - The specific surface, which is the ratio of the surface area of the particles to their volume, is an important factor to be considered because as the specific surface increases, for a constant water/cement (w/c) ratio, the compressive strength will decrease. Table 2 illustrates this relationship and the corresponding effect on the fresh concrete density.

Table 2 : Specific Surface of Aggregate and Strength of Concrete for a 1:6 Mix with at w/c Ratio of 0.60

Specific surface of aggregate	28-day compressive strength	Density of fresh concrete
m ² /kg	N/mm ²	Kg/mm ²
2.24	36.1	2330
2.80	34.9	2325
4.37	30.3	2305
5.71	27.5	2260

(A. M. Neville, Properties of concrete, Pitman, 1981 (Third edition), after A. J. Newman and D.C. Teyehenne, A classification of natural sands and its use in concrete mix design, ibid., pp. 175-93)

Shape and surface texture - The shape characteristics of fine aggregate can have an appreciable effect on the properties of fresh and hardened concrete. The more rounded aggregates will result in improved workability whereas flaky/elongated particles reduce workability. Moreover, it can be shown that the percentage voids content of an aggregate will increase as the aggregate particles become less rounded. Therefore, if the shape of a fine aggregate is expressed in terms of its percentage voids in a loose condition then it is to be expected that as the void content increases the water content of the mix will also increase. This effect can be seen in Figure 1.

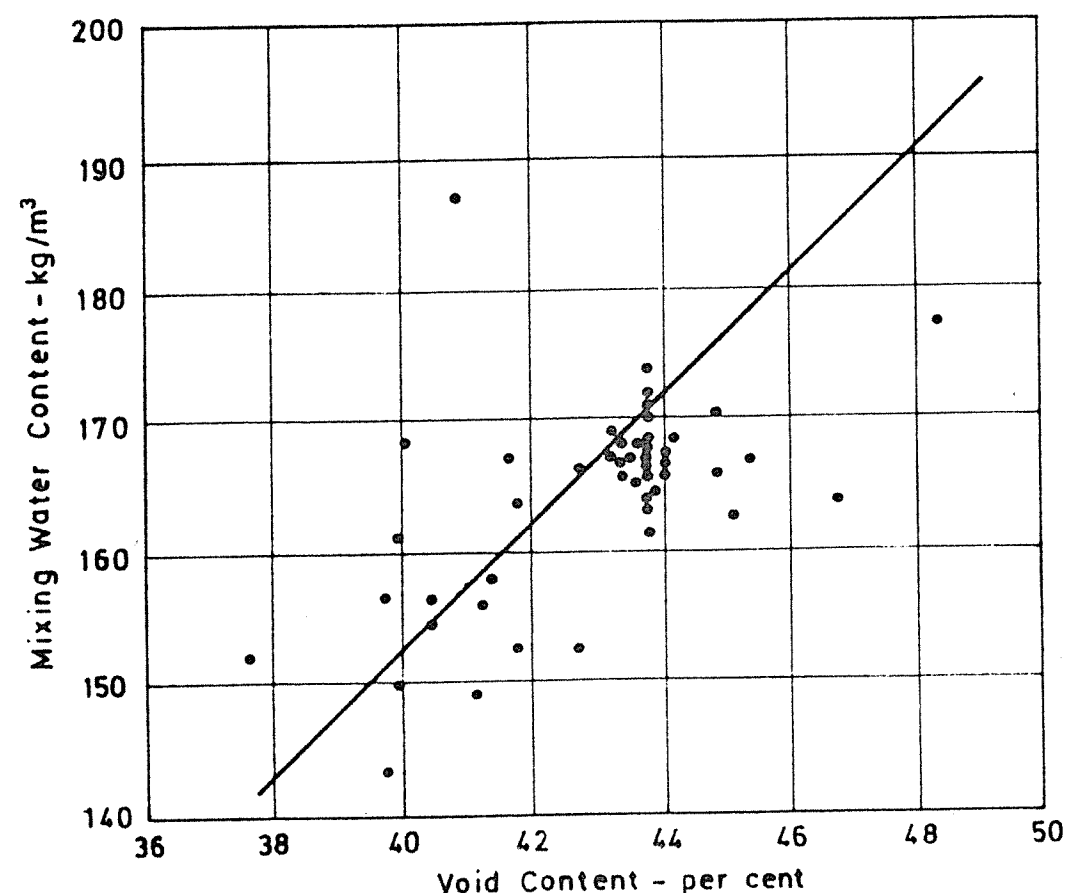


Figure 1 : Relation between void content of sand in a loose condition and the water requirement of concrete made with the given sand (A. M. Neville, Properties of Concrete, Pitman, 1981 (Third edition), after D.L. Bloem and R.D. Goynov, Effects of aggregate properties on strength of concrete.)

The surface texture can also affect the compressive strength of concrete but this is unlikely to be a consideration unless high-strength concrete, say $> 60 \text{ N/mm}^2$, is required. However, it is advisable to pay particular attention to the surface condition of crushed rock fines because dust particles will most likely have adhered to the surface of the larger

particle sizes. This may reduce the bond with the cement paste and also require a higher water content resulting in a lower compressive strength. Furthermore, care must also be exercised when testing crushed rock fines to ensure that the grading of the aggregate is determined by wet sieving rather than dry sieving. An illustration of the likely errors is shown in Table 3.

Table 3 : Grading comparisons for crushed rock fines

Sieve size	Percentage by weight passing		
	A	B	C
10.00 mm	100	100	100
5.00 mm	99	100	100
2.36 mm	88	89	86
1.18 mm	59	64	57
600 μm	39	45	34
300 μm	26	32	18
150 μm	17	23	7
75 μm	11	17	0

(Aggregates : Sand, Gravel, and Crushed Rock Aggregates for Construction Purposes, Geological Society, Engineering Geology Special Publication No.1. 1985.)

where :-

- A - Apparent overall grading determined in accordance with BS 812:Part 1:1975, Clause 7.1.4 (Dry sieving)
- B - True overall grading determined and calculated, in accordance with BS 812:Part 1:1975, Clause 7.1.6 (Wet sieving)
- C - Grading of material excluding $-75\mu\text{m}$ fraction determined in accordance with BS 812:Part 1:1975, Clause 7.1.6

Dust and silt/clay content - As stated previously the dust content will affect the workability. For example an increase in the dust content from 0 to 20 percent, when expressed as a percentage of total aggregate, for a medium grade fine aggregate, would require a 5 - 10 percent increase in the water content to produce a given workability. Whilst dust is unlikely to be a problem with naturally occurring sands the presence of clay and silt may produce similar effects to those described above.

Relative density - Whilst it is unusual for specifications to specify a value for the relative density it is, nevertheless, an important property for the purpose of mix design. This is particularly so with the change in recent times to gravimetric mix design. Of the three most commonly used relative densities namely : oven dry, saturated surface dry, and apparent,

it is the saturated surface dry value which is most commonly used in mix design. This is because the water contained in all the pores in the aggregate does not take part in the hydration of the cement in a concrete mix. Whilst differences between the three densities are small in the case of aggregates with a low water absorption value the differences are substantial for aggregates having a high water absorption value. This effect is illustrated in Table 4.

Table 4 : Relative density comparisons for various aggregates

Water absorption %	9.5	3.7	1.6	0.6	0.2
Relative density*					
- Oven dry	2.03	2.36	2.67	2.68	2.73
- Saturated surface dried	2.23	2.45	2.72	2.70	2.74
- Apparent	2.52	2.59	2.79	2.73	2.75

* As determined in accordance with BS 812:Part 2:1975

(Aggregates : Sand, Gravel, and Crushed Rock Aggregates for Construction Purposes. Geological Society, Engineering Geology Special Publication No.1, 1985).

Deleterious substances - As deleterious substances are more likely to be found in natural sands rather than crushed granitic fine aggregates the following should be checked :

(a) Organic impurities - Sands should be checked for organic impurities because their presence may impair the hydration and lower the ultimate strength.

(b) Unsound particles - A petrographic examination should check for mica, chalk and sulphates in particular. Whilst BS 882:1983 does not specify limiting values for their content the general rule of the less the better should be observed. In the case of sulphates, however, guidance is given in BS 5328:1981 which recommends a maximum sulphate content of 4 percent by weight of cement.

(c) Salt contamination - Aggregates won from the sea irrespective of their original mode of occurrence will contain chlorides. The quantity of chloride in an aggregate will depend, among other things, on its origin. Sands taken from the foreshore will have the highest concentration and buried sands of alluvial origin may be expected to have the least. Whilst the presence of chlorides in aggregates will not normally be a problem for plain concrete, in fact it can make the concrete stronger at an early age, the opposite is true for concrete containing embedded steel.

There are, however, widely differing opinions as to the amount of chloride that can be tolerated in concrete containing embedded steel. As stated previously BS 882:1983 does not specify limits for the content of chlorides in aggregates but provides guidance in the form of an appendix. These values are shown in Table 5.

Table 5 : BS 822:1983 (Appendix V) Chloride content guidance values

Type or use of concrete	Maximum total chloride content expressed as percentage of chloride ion by mass of combined aggregates
Pre-stressed concrete	0.02
Steam-cured structural concrete	
Concrete made with cement complying with BS 4027 or BS 4248	0.04
Concrete containing embedded metal and made with cement complying with BS 12	0.06 for 95% of test results, with no result greater than 0.08

As stated previously the Public Works Specification imposes limits for the chloride content permitted in the concrete expressed as the maximum chloride ion content by weight of cement. Compliance with these limiting values requires tests on the hardened concrete. Clearly it is the total chloride content of the concrete which is the limiting factor and not the chloride content of the aggregate. In practice the amount of chloride ion contained in the other constituents is small and for all practical purposes in Hong Kong their chloride content may be ignored. However, care should be exercised when deciding on which test method should be adopted to determine the total chloride content in aggregates because the water extraction method may give a much lower value than the acid extraction method.

A further consideration when using aggregates containing chlorides is that salt, being hygroscopic, will absorb moisture from the air and cause efflorescence of the concrete surface. In situations where aesthetics are a prime consideration then the use of sands containing excessive chlorides should be avoided.

Alkali-aggregate-reactivity - No technical paper on concrete aggregates would be complete without reference to this important topic. In view of the catastrophic effects that certain reactive materials can have on hardened concrete i.e. the expansion and subsequent cracking which may impair the structural integrity of a building, it is imperative that a thorough petrographic examination to identify potentially reactive materials should be carried out in accordance with ASTM Standard C295-79.

However, as a petrographic examination will only identify the presence of materials with the potential for reaction, long term expansion tests such as the mortar-bar test should be undertaken if reactive minerals are present. Whilst no guidance is given in BS 882:1983 on the interpretation of test results recommendations are given in the Cement and Concrete Working Party Report on The Diagnosis of Alkali-Silica Reaction, Draft for Comment, February 1987. It is interesting to note that the Working Party stresses the need to examine fine aggregates because present indications are that reactive fine aggregates may be just as damaging to concrete as reactive coarse aggregates.

Abrasion resistance - In situations where the surface of concrete is required to have a high level of skid and wear resistance the most important constituent in the mix is the fine aggregate. Examples of such usage are roads, runways and industrial floors. The importance of the fine aggregate in concrete is in contrast to the requirements for bituminous road surfacings where the polishing characteristics of the coarse aggregate plays a significant role.

Research in the early seventies on the influence of materials and mix design on the skid resistance of concrete road surfaces at the Cement and Concrete Association (UK), by Maynard and Weller (1970), produced a number of important findings.

Namely:

- (a) the grading of the fine aggregate had very little influence on the skid resistance value;
- (b) the use of natural sands always yielded higher skid resistance values than crushed rocks;
- (c) the hardness of the sand was the most significant factor;
- (d) fine aggregates obtained from the crushing of road stones yielded low skid resistance values and were not recommended for use in the surface of a concrete road.

It is clear from the foregoing that the use of natural sand fine aggregates should produce concrete surfaces with greater wear and skid resistance characteristics. The results of tests undertaken on natural river sands from the PRC as compared to crushed rock fines in Hong Kong have confirmed this fact. The results are shown in Table 7.

Test results on fine aggregates

The results of a limited testing programme carried out by the Author on locally produced crushed rock fine aggregate, local marine and alluvial sands from boreholes south of Tsing Yi Island, and river and marine sands from the PRC are as shown in Table 6, and Figures 2 and 3.

Table 6 : Summary of testing of fine aggregates available in Hong Kong.

	Type of fine aggregate				
	Marine sands	Marine sands (PRC)	Alluvial sands	River sands (PRC)	Crushed rock fines
Chloride content as Cl % (BS 812:Pt.4 :1976)	0.23-0.35*	0.01-0.18	0.05-0.33*	<0.01	<0.01
Sulphate content as SO ₃ % (BS 1377:1975)	0.04-0.11	0.12-0.16	0.01-0.06	<0.01	<0.01
Shell content % (BS 812 Pt. 106:1985)	0.30-17.90	0.90-39.40	0.01-0.28	<0.01	<0.01
pH (BS 1377 :1975)	7.50-8.40	8.30-8.70	7.10-8.30	6.60-8.30	-
Organic matter content % (BS 1377 :1975)	0.05-0.19	0.04-0.07	0.01-0.08	0.01-0.03	<0.01
Water absorption % (BS 812: Pt.2:1975)	0.40-0.60	0.40-0.60	0.40-0.60	0.40-0.60	0.40-1.80
Specific gravity (BS 812: Pt.2:1975)	2.62-2.65	2.63-2.66	2.61-2.62	2.61-2.62	2.56-2.63

Notes :

1. With the exception of the water absorption and specific gravity tests, where only 2 samples were tested, the following numbers of samples were tested for each type of fine aggregate :

Marine sands	4	Samples
Marine sands (PRC)	5	Samples
Alluvial sands	7	Samples
River sands (PRC)	4	Samples

2. The test results for crushed rock fines (Mt. Butler Quarry) are the monthly average values obtained from routine quality control testing between August - October 1987
3. The samples of the marine and alluvial sands were obtained in September 1987, from boreholes drilled in an area south of Tsing Yi. (Whiteside 1987).
4. The origin of the marine sands (PRC) and river sands (PRC) is unknown but the marine sands are understood to be obtained from beaches. Samples obtained from Sand Depots at Chai Wan, Kowloon Bay, Lai Chi Kok, Shatin and Tai Lam Chung. Date of sampling October 1987.
5. The chloride determinations for marine and alluvial sands shown thus * were made on samples taken directly from marine boreholes. Preliminary indications are that the chloride content may be reduced by approximately 25 percent if supernatant water is allowed to drain prior to testing.

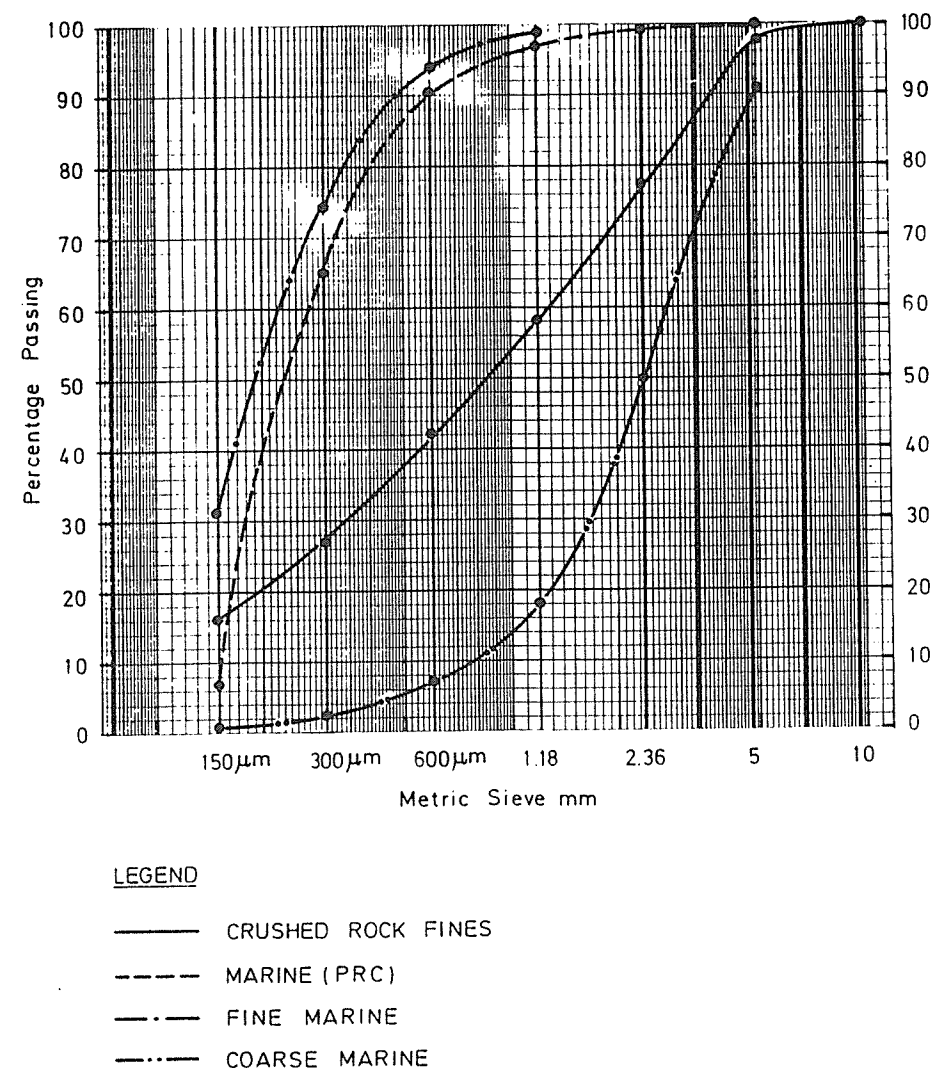


Figure 2 : Grading curves for marine sands (Hong Kong), marine sands (PRC), and crushed rock fines.

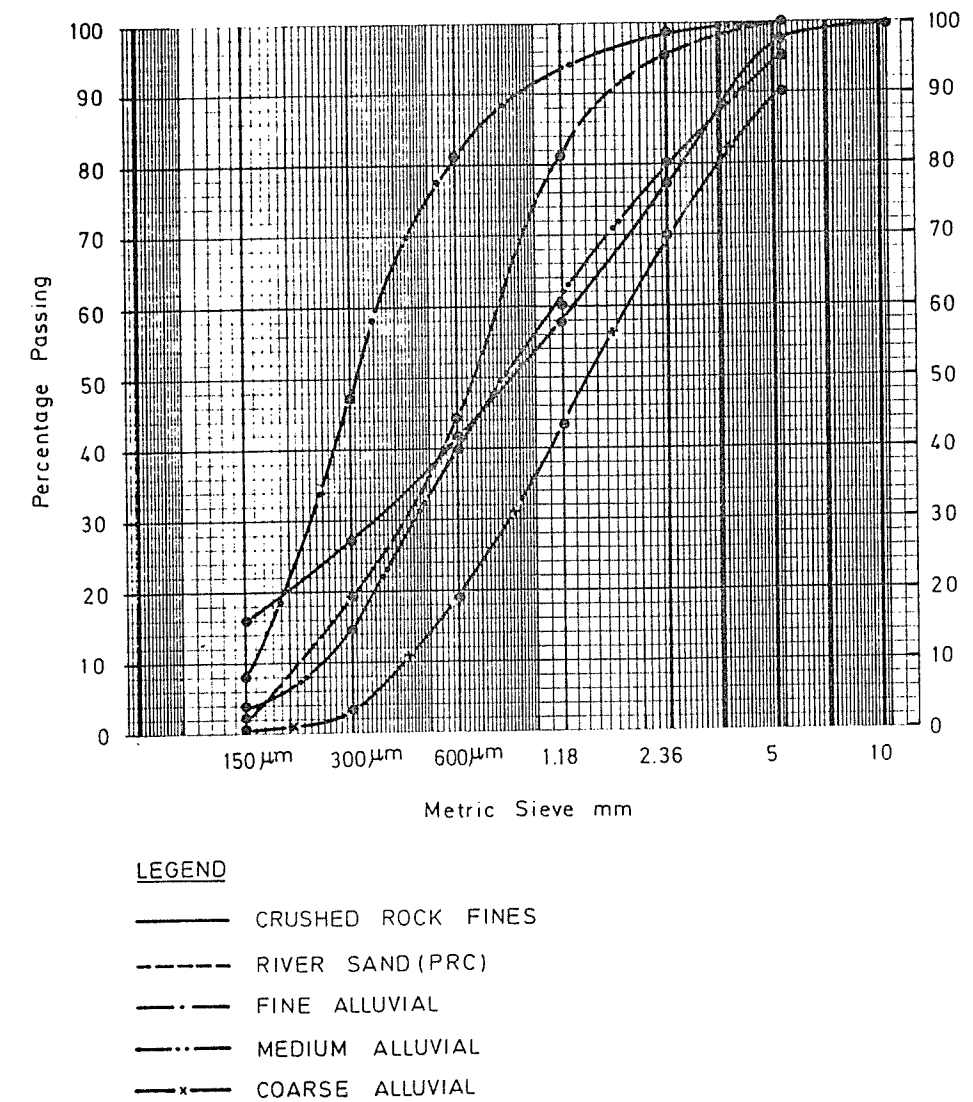


Figure 3 : Grading curves for alluvial sands (Hong Kong), river sands (PRC), and crushed rock fines

The results of an Accelerated Wear Test programme initiated by the Author are shown in Table 7. In considering the test results the following definitions of the materials tested are relevant :

- Crushed rock fines : Fine aggregate produced by the crushing and processing of (granitic) rocks
- "River" sands (PRC) : A natural sand dredged from rivers in the PRC. Origin unknown.
- "Marine" sands (PRC) : A natural sand dredged from coastal waters of the PRC. Origin unknown.
- Alluvial sands : A sand originally laid down in fresh water conditions but may currently be under the sea.
- Marine sands : A sand deposited in marine conditions.

Table 7 : Accelerated Wear Tests carried out on some Hong Kong Crushed Rock Fines by the Cement and Concrete Association (UK) in 1980, (Samples:A-D), and River Sands (PRC), (Samples E-H), by the Department of Transport, Quality Assurance and Materials Testing Laboratory, Ruislip (UK) in 1983.

Sample	Fine aggregate		Texture depth (mm)		Skid resistance value (SRV)	
	Type	% of total aggregate	Initial	Final	Initial	Final
A	Crushed rock	35	1.08	0.46	89	53
B	"	35	1.14	0.56	88	49
C	"	35	1.18	0.43	82	49
D	"	35	0.99	0.32	92	45
A	"	40	0.81	0.47	96	50
B	"	40	0.90	0.61	96	51
C	"	40	0.54	0.26	86	43
D	"	40	0.57	0.34	88	45
E	River sand (PRC)	35	0.90	0.40	-	56
F	"	35	0.94	0.52	-	57
G	"	35	0.83	0.40	-	54
H	"	35	0.79	0.43	-	56
E	"	40	0.81	0.40	-	60
F	"	40	0.88	0.48	-	58
G	"	40	0.79	0.43	-	55
H	"	40	0.82	0.39	-	53

Notes :

1. Each sample comprises four specimens and the results quoted are the average of the four test results.
2. Crushed rock coarse aggregate obtained from Cha Kwo Ling Quarry was used in both series of tests.
3. Samples A to D comprise crushed rock fines and were obtained from four separate sources within Hong Kong in 1980.
4. Samples E to H comprise river sands (PRC) and were obtained from sand depots in Hong Kong in 1983. The origin of the sands is unknown.

Discussion of test results

Based on the preliminary results of limited testing, the use of the natural sands from the boreholes South of Tsing Yi as a fine aggregate in concrete and mortar, appears technically feasible. The medium and coarse alluvial sands tested are generally well graded and would be most suitable for general concreting work. The medium graded alluvial sands tested are similar to the River Sands (PRC) but with slightly better grading characteristics. The fine alluvial sands should be suitable as a mortar sand etc. The fine marine sands tested are generally finer than the Marine Sands (PRC) but may be still suitable for use as a fine aggregate in mortar etc. The coarse graded marine sands are unlikely to be suitable as a fine aggregate in concrete because of their poor shape characteristics and extreme coarseness.

The presence of chlorides in the sands is not considered an inhibiting factor to their use because the chloride concentration can be reduced to acceptable levels by washing, or possibly by natural drainage in stockpiles.

The loss-on-ignition, pH and organic matter results are all generally satisfactory and should not present a problem. The sulphate content is very low and should ensure that the BS 5328: 1981 limit of 4 percent by mass of the cement in the mix is not exceeded. However, it should be noted that it is the total SO₃ content in the mix that should be checked. Therefore, if materials which may have a high SO₃ (e.g. PFA) are used in the mix then the total sulphate content of all the constituents in the mix should be calculated.

The shell content, and hence the acid soluble material, is high in the case of the marine sands and they may not be suitable for use in concrete where heavy surface wear is expected and a high resistance to abrasion is required (e.g. industrial floors).

The preliminary petrographic examinations on the alluvial and marine sands have revealed that the majority of the component particles are satisfactory. The presence of coal, gypsum, mica, iron pyrites and marcasite was not detected. With regard to alkali-silica reaction (ASR), the reactive forms of silica namely, opal, chert and flint were not detected. The sands so far examined, therefore, may be regarded as non-reactive.

It is understood that the non-availability of a local source of natural sand was one of the reasons why hot rolled asphalt has not been specified for general use. Preliminary indications are that it should be possible to produce a natural sand that satisfies the BS 594:Part 1: 1985 requirements for fine aggregate in hot rolled asphalt.

Future research

Before any proposed aggregate source being considered for use as a construction material can be accepted it is imperative that a full test programme should be carried out.

Promising areas for future research on natural sands are the use of such materials in concrete, mortar and bituminous pavements. With regard to concrete such studies should cover the rheology of fresh concrete and

the properties of hardened concrete. The following effects on concrete containing natural sands could be studied :

- (a) workability and mix proportions
- (b) setting time
- (c) compressive and tensile strengths, and in particular with regard to early and long term strengths.
- (d) shrinkage
- (e) absorption and permeability
- (f) creep
- (g) accelerated wear wheel tests
- (h) chlorides

With regard to mortars trial mixes could be undertaken to determine optimum grading characteristics, mix proportions etc., for use in masonry, rendering and plastering, and floor screeds. The effects of particle size, particle shape, cleanliness and impurities, particularly chlorides, should also be studied.

With regard to bituminous materials a study could be undertaken to determine the economic and technical feasibility of producing Hot Rolled Asphalt (HRA) to BS 594. The passage of time has shown the success of the HRA surfacing to the Cross Harbour Tunnel and its approaches.

Other uses for sands could also be considered and the production of glass mosaics and tiles, and also filter drains, are a few possibilities.

Acknowledgements

The author would like to thank the Director of the Civil Engineering Services Department for permission to publish this paper. The considerable part played by the staff of the Site Investigation Section and the Laboratories Section of the Materials Division, Geotechnical Control Office, without whose assistance this paper could not have been produced, is gratefully acknowledged. The assistance of the Director of Highways for allowing the use of material previously obtained by the author during the time he served with the then Highways Office is also gratefully acknowledged. It should be noted that the views and opinions expressed are the Author's, and may not represent Government policy.

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APPENDIX

Extract from Hong Kong Government's Public Works Specification

(a) Concrete (Structural)

Clause 26.08 (part) : Fine aggregate shall consist of crushed rock as for coarse aggregate or of clean sand. The grading shall lie within one of the limits of grading zones 1, 2 or 3 of Table 2 of B.S. 882 and, in the case of crushed rock, not more than 20 percent by weight shall pass a 150µm B.S. sieve; or for crushed rock fines only within the limits shown in Table 26.08.

Table 26.08

B.S. 410 test sieve	Percentage by weight passing B.S. sieve
mm	
10.0	100
5.0	85 - 100
2.36	60 - 87
1.18	40 - 67
µm	
600	20 - 50
300	5 - 25
150	0 - 20

Clause 16.06 Chloride Content : The total chloride content of the concrete shall not exceed the limits shown in Table 16.4 expressed as a percentage relationship between chloride ion and weight of cement in the mix.

Table 16.4

Type of concrete	Maximum total chloride content %
Prestressed concrete. Steam cured structural concrete	0.1
Reinforced concrete. Concrete with embedded metal	0.35

(b) Concrete (Carriageway)

Clause 10.29 Materials (part) : Fine aggregate shall be natural river sand.

Clause 10.30 Chloride Content : The total chloride content of the concrete for reinforced carriageway slabs shall not exceed 0.35 percent when expressed as a percentage relationship between the chloride ion and the weight of the cementitious content of the mix.

(c) Bituminous Materials

Clause 26.07 Aggregate and Bitumen for Bituminous Materials, Bituminous Emulsions and Primecoating Material : Fine aggregate for roadbase and flexible surfacing shall be that material less than 5 mm size consisting of crushed rock fines, clean river sand or a blend of the two materials. Water absorption of fine aggregate shall not exceed 2 percent.

(d) Sand

Clause 26.54 Sand :

(i) Sand for mortar, plaster, screeds, rendering etc., shall comply with the relevant sections of BS1198, 1199 and 1200.

(ii) Sand for concrete shall comply with Clause 26.08. Marine dredged sand shall not be used for concrete without the Engineer's prior written approval.

(e) Mortar

Clause 26.39 (Part) :

(i) The sand shall be natural sand or crushed natural stone or a combination of both to BS 1200.

Specifications for Reclamation Fill

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SUMMARY This paper is aimed at identifying the pitfalls in developing a "General Specification for Reclamation Fill" and examining practical aspects of the dredging process which constrain design and specification.

Introduction

It can be said straightaway that there are no "Standard Specifications" for reclamation fill. That said, the author will not be surprised to be confronted with one!

In this paper "fill" and "reclamation" are to be understood as marine related, and "dredging" and "reclamation" to be so closely interrelated that the use of one or other word implies both activities.

A very useful starting point for anyone looking for guidance on this subject is "Dredging : A Handbook for Engineers" by Bray (Bray, 1979). Chapter 10, "Reclamation" gives very useful and practical guidelines the author uses as an "aide-memoir" for his own work and is happy to acknowledge may be repeated paraphrased in this Paper.

A second reference which should be useful as a general reference is the BSI "Code of Practice for Maritime Works, Section 5, Dredging and Reclamation", which is to be published shortly (British Standards Institution). However, in the author's opinion all Codes tend to become Rule Books requiring little or no further thought on the part of the user whereas it is essential in marine work and especially dredging work, to start each project with an open mind and a clean sheet of paper.

There are other documents and references which will be mentioned in due course but they are either peripheral or very specific indeed. Very specific means in this context, related to a known situation which almost certainly is not exactly duplicated elsewhere and therefore can be very misleading if applied elsewhere.

Fill for what?

When considering the drafting of a specification one must first look at the purpose of the exercise. That is, what is the ultimate end-use? The end-use encompasses a very wide range of uses, from "where can we

dump the dredgings?" to "we need a container terminal yesterday". The former "use" is not uncommon in Western Europe and the U.S.A. where the pressing need to dredge shipping channels combined with the ever increasing restrictions on sea dumping at ever increasing distances leads one to look at formerly uneconomic methods of "dumping" on land. This activity also has restrictions of course.

The latter "use", the need for land in a hurry, also arises and demonstrably so in Hong Kong. Even in Hong Kong there is a range of uses from immediate to within a few years, say five. Forecasting further than five years ahead is, the author believes, interesting but not very reliable. So, now let us look at reality.

When trying to specify fill material one should look at the whole, that is the underlying in-situ strata and the final, surfacing. The fill can be thought of as the usually very thick meat in the sandwich, but nevertheless only part of the whole.

Very typical of Hong Kong is the immediate situation. Original in-situ bed material is usually of very poor quality and at once one comes into a circular sort of argument with no clear starting point. From a (civil) engineering point of view the best thing to specify is that all poor material be removed and be replaced by good material. On the other hand it is obviously(?) much easier to dump good material on top of the poor in-situ sea bed and allow for consequent settlement.

If one chooses to remove poor in-situ material perhaps it can be replaced by less-than-good but better material. If the choice is to dump on top of poor material perhaps some uncertainties can be removed by specifying particularly good material.

On the face of it, the above are fairly straightforward if laborious comparisons to make. However, do we have first class material available? Have we anywhere to dump bad material? What class of material is, in reality, available? Hence the "circular" argument.

A "good" fill should be predominantly granular, that is fairly obvious. However a 100% granular fill can be less than ideal. A fill entirely made up of snooker balls would be certainly granular but hardly a good fill.

Staying with the "immediate" scenario, let us forget for the moment the question of whether or not to remove poor in-situ ground, and look at the topside. If the requirement is for heavy use, e.g. airport runways, container stacking, heavy industry, the top layer of the "sandwich" is likely to be in any case pretty robust, probably a metre or more of various finishing and wearing layers. Would another 10cm of hard core or even asphalt be more expensive than an upgrading of the general fill? Expensive is of course a relative term, optimum is a better adjective. A relevant example of "immediate use" is that of the new container berth, Trinity Terminal, at the Port of Felixstowe, U.K. (and now, be very well aware of the warning about specific examples). This is similar to a typical Hong Kong situation. The privately owned Port of Felixstowe is perhaps the U.K. equivalent of Kwai Chung. There was a very limited amount of land available within the Company's jurisdiction and the commercial pressures to provide additional facilities overwhelming. The result is a container terminal built upon several metres, up to eleven, thickness of tidal mudflat with a flexible working surface and none of the original bed material removed. The meat in the sandwich is the "arisings" from the necessary deepening of the approach channel. Unsuitable dredged material was dumped at sea but all suitable spoil was pumped ashore on top of the mud. The spoil is in fact rather good, a frequent concomitant of the dredging being difficult! In this case multiple beds of gravel, coarse sand and massive slabs of limestone which were easily distinguishable from

the "unsuitable" stuff. Thus the specification of the marine fill was in fact very good. Nevertheless settlements in excess of two metres have been predicted and allowed for in the overall design. The deciding factor is that the owner has use of his facility much sooner and at lower first cost than if the best engineering solution had been adopted. The author is sure that the consultants (Posford Pavry), and the contractors (Kier), will be pleased to give more detailed information.

In complete contrast, let us look at the "reclamation" carried out by the Manchester Ship Canal Company (M.S.C.). Maintenance dredging is continuous and unavoidable. In a reverse of the usual situation the seaward end of the Canal silts up with fines brought in through the entrance locks whereas it is the upper reaches which receive deposits of quite heavy sand from the feeder river especially during periods of high flows. To transport the dredged spoil to sea is a round trip of up to 120 miles and possibly five sets of locks. The spoil is therefore pumped ashore at several sites along the Canal. For many years the areas were considered to be of no use at all, indeed to be positively dangerous to any body or animal straying onto the surface. In fact because of the practice of using spoil dumps in rotation rather than trying to fill one before starting on another, the surface layers have dried out by a mix of very slow drainage and relatively fast evaporation assisted by transpiration as vegetation is established. The silt areas can now be used for grazing, sporting activities and limited cultivation. One of the sand areas is also being exploited as a sand pit to the M.S.C. Co's profit. Those are examples from each end of the range of uses, and there are very many variations and combinations in between. Rarely will there be two situations the same, remember the advice in the Introduction and start every job with a clean sheet of paper.

One must also distinguish between fill which is to be placed under water and fill which is to be placed above water level. Reclamation which starts from below water level is likely to be required for immediate use, e.g. Trinity Terminal, Kwai Chung Terminal 6, Sha Tin - Tai Po Road and the like. However, there are situations where reclamation is required to raise the land surface from at or near water level to a height safely above flood level or, as already described, simply as a land dump for dredged spoil.

Fill from where?

From wherever you can get it! In practice one often does not have much choice. Returning to our previous examples at Felixstowe there were a few options. Firstly, the import of fill of reasonable uniformity and good quality from offshore deposits in the North Sea, secondly, one could use the whole of the channel dredging spoil and work on its estimated average quality, thirdly, and the chosen method, one can make selective use of the dredged spoil, and finally, one could use a combination of sources. It should be noted that dredging works had been carried out for many years prior to the Trinity Terminal project so a reasonably reliable comparison of the options could be made.

The Manchester Ship Canal had effectively no options at all and really quite fortuitously found itself with usable fill.

Well what would we like to have? Let us have a look at the soil type shown in Table 1.

Table 1. Classification of hydraulic fills according to soil type. (Table 10.1, reproduced from Bray, 1979)

Soil type	Characteristics of fill
Soft sedimentary rocks	Good, but fragments should be kept small and mixed with finer material. Some siltstones decompose and produce fines. Natural compaction occurs relatively easily and quickly during drainage of the fill
Boulders and cobbles	Reasonable if mixed with finer material. Large boulders should not be allowed. Upper layers should be graded.
Gravel	Excellent
Sandy gravel to medium sand	Good. Compacts well if well-graded.
Fine sands	Reasonable. Must be well-compacted to achieve high densities in earthquake areas to avoid liquefaction
Silts and muds	Very poor. Very weak as placed and drains slowly. Consolidation takes years.
Soft cohesive soil	Laminated fill, usually under-consolidated after placing. Takes a long time to consolidate.
Silty or clayey sand	Very heterogeneous fill of large void ratio. Consolidation rate increases with higher permeabilities
Stiff cohesive soil	Skeleton of clay balls in matrix of sand and clay. Consolidation period variable depending on proportion of sand and clay

The author's preference would be for mostly "sandy gravel to medium sand" with a bit of "gravel" to bulk it up and a little "fine sand" and "silts" to make it stick together and be not too lively to walk and drive on. Not a very high-tech description but one would hazard that most people know exactly what is meant! The author would not describe "gravel" as "excellent" because of the possible "snooker ball" effect mentioned earlier. Nevertheless, it is undoubtedly "good", but one would like to have a little bit of sand mixed with it.

However, remember that some reclamation starts above water level and nearly all reclamation finishes above water level so perhaps one can consider the less than "good" materials for this type of fill.

In the author's opinion it is self evident that for fill which is to be placed underwater one should specify a substantially granular material. Setting aside geotechnical considerations, the mechanics of the dredging process will render cohesive soils useless because they are produced in the form of a slurry. The consistency of the slurry can range from dirty water to extremely lumpy custard but as you can see neither version will be of much use after being thrown back into the water. For above water level one can consider almost all materials, and again one can probably set aside immediate geotechnical and dredging considerations and first establish the time and end-use restraints. Given time, even the softest of cohesive fill materials will consolidate naturally, as demonstrated by the Manchester Ship Canal. Given assistance in the form of carefully controlled filling in thin layers, ploughing techniques, sophisticated drainage systems, specialised agriculture etc the process can be speeded up. These techniques are used by the Municipality of Rotterdam (the port authority for Rotterdam) to dispose of their silt dredgings on land which is improved by raising but is nevertheless in great demand for the further development of the city. The nearest comparable situation in Hong Kong and known to the author would be Tin Shui Wai but typically the pressure for development land is even greater than in the Netherlands, so there is probably insufficient time for consolidation using even the above sophisticated techniques.

So far we have not really addressed the question "Fill from Where?" but now, having looked briefly at the materials one would like to or may have to use, let us have a metaphorical look around for them.

First of all, it is advantageous to know something about dredgers and dredging techniques simply because they have a very direct influence upon the determination of whether a seabed deposit is suitable and accessible and whether the deposit in its delivered form is acceptable. Probably the first and easiest parameter to check is the depth of water at the borrow site. If it is greater than 30 metres, take further specialist advice! Next, be sure that even if existing water depth is not too great, that sufficient acceptable material lays above the -30m. contour. Conversely, if water depths are less than 10m, operational restrictions will again start to appear. That is not to say that outside these limits dredging is not possible, only that the choice of dredger type and size becomes progressively more restricted with consequent increase in cost. Another parameter especially important here is the type and density of marine traffic. The "hazard" factor of dredging operations should not be overrated, dredgers are, after all, ships albeit sometimes hard to recognize as such, and are from their very nature designed to work safely at sea and in harbours. Environmental factors must not be overlooked nor hazards over-rated. Dredgers are no noisier than other ships and "pollution" from spoil overflows is very short term, short range and by the in-situ material in any case. Now at last we can begin to look at the

material itself.

To look at potential borrow material one has to rely on really a minute sample of the total volume and its correct correlation with the borehole data with which it is usually associated. There are never enough boreholes. Primarily one is looking for evidence that the material is predominantly granular and at reconnaissance stage one need not worry too much whether it homogeneous, in layers, pockets or whatever. The ways of getting hold of samples and their testing are discussed in other Papers.

Having found an area where all the above factors have been examined and the results are favourable, one should look at the same factors at the site of the reclamation. Water depths should offer no problems either way, but reclamation that is some distance inland could obviously benefit if the dredging plant can get as close to the shore as possible. Environmental aspects may need more careful consideration. For example, it maybe desirable to use fill from a borrow with a high "fines" content and rely in part, on the washing out of the fines with the returning runoff water. This can cause problems on inland sites where the return water is discharged to an inland drainage system. On the other hand one may be lucky enough to have a very coarse borrow with plenty of gravel and cobbles. However, the noise that such a mixture can make passing through a pipeline is noticeable to say the least! The consequence may be that night work is not permitted with consequent very significant cost increase. So whilst one would not wish to waste ones apparent good fortune, a specification which rigorously excludes any fines may not be such a good idea. If the situation allows, it is always a good idea to have alternative fill areas for "good" and "poor" material or purely for operational/environmental reasons such as above. At the other extreme, silt and soft clays are very easy and very quiet to pump, but if from harbour or river sources can produce an unmistakable stink. Essentially an ephemeral problem but if you have to use such material try and find an area of reclamation downwind of the local EPD office !

The specification

All the foregoing is to try and illustrate to those without dredging experience that there are many literally hidden factors which should be taken into account before the usually very simple specification is written down.

"Overspecifying" in dredging work does not pay. The degree of quality control available for land operations is not available in dredging work. The dredgers themselves can be highly sophisticated digging machines with their own machinery and movements under very rigorous quality control as their contractor owners will proudly demonstrate. The trouble is, we can't see what we're doing until we've done it!

However, the author has to say that from his small knowledge of the quality demanded for typical Hong Kong reclamation, no dredging contractor should have any qualms about delivering a superior job.

Rather perversely, the variety and generally low quality of land source fill in Hong Kong makes it quite difficult for an outside specialist such as the author to convince a client that marine fill is generally of good quality, or better say, up to specification: uniform and requires only simple control procedures.

The author has seen a number of typical local specifications for land

fill. An important feature is the number of classes of fill, together with the long period of notices to be given for examination and testing from the Contractor and the equally lengthy periods for the Consultant to carry out tests and give approvals. This point is made deliberately, to draw attention the possibility of misunderstandings even between people with a common aim. Current Hong Kong practice for filling is that the material arrives in small parcels at a slow rate in vehicles or vessels from which sampling for inspections can fairly easily be carried out. As all interested parties are now aware, marine fill comes in very large parcels at a high rate and in or from vessels which do not lend themselves to

recovery of samples. They are also very expensive to operate and even more expensive not to. The leisurely procedures of notices and approvals simply cannot keep up with the rate of progress. So we must think of, and specify, simple and fast procedures.

One can dodge the issue and simply state that the contractor must find material on his own account, which when finally placed meets a certain specification and which will be tested by a number of full depth boreholes, and approval given after reclamation is reported as complete.

This is hardly calculated to attract a low price. For a small job, say 100,000 cu.m. or so, which for some reason is being done by a very large dredger, this may in fact happen. Remember that the larger trailer and cutter dredgers can deliver 500,000 cu.m. per week in the right circumstances, so it could all be over within the week. (the author has direct experience of at least one job like that).

At the other extreme, the client can accept most of the risk and specify that all material from within a designated borrow area is deemed to be acceptable (don't forget to delineate the borrow in the three dimensions). One would not really want to do this either. Not because it is not practical, oddly enough it is, but only if the employer/consultant is so conversant with the practical management of dredging works that he can write a specification which in effect is an instruction manual telling the Contractor exactly where to dredge, how, with what and so on. All the requirements can be easily monitored. One simply duplicates the Contractors routine management procedures. Now if one knows so much about the business you might as well do it yourself. And that is also a serious alternative for organizations such as port authorities who operate their own dredgers for maintenance dredging and can charter in additional plant to carry out capital work, not really a realistic option in Hong Kong however.

Of course the solution is somewhere between the two extremes. A question which the Consultant cannot altogether dodge, except in the "everything at Contractor's risk" option, is what proportion of the borrow material will actually end up in the fill? Even if he is only answering this question at the preliminary planning and budgeting phase, it can be very important, if for example the quantity of suitable material appears to be barely sufficient. Bear in mind that marine reclamation works are often measured in the tens of millions of cubic metres, so even a small percentage error in the estimate could lead to the use of substantial quantities of more expensive fill. In truth, it is a very difficult estimate to make and specialist advice is advisable. Not that we specialists have any secret formulae either, just more experience of best guesstimating.

Common sense tells us that a borrow area with very coarse material will give rise to minimal losses between in-situ and in-fill volume. However, some losses will occur even if it is only loss of fines created by the mechanical damage inflicted whilst passing through the dredging machinery. And that depends on the quality of the rock from which the material is

derived, yet another difficult question. There will also be very small losses of even the coarsest material carried away by the force of the pumping water. After all, that 10% loss should be safe enough!

As material becomes finer and/or more mixed, an increasing proportion is lost somewhere along the line. In a typical mix of seabed material which can be found in Hong Kong waters, one could say that one will lose the 10% of the coarser fraction, and perhaps half of the silt and clay fraction up to a maximum, where the silt and clay fraction is around 50% of the whole. In-situ percentages of fines (i.e. silt and clay) in excess of around 50% can certainly be "washed" down to any desired level or completely away, but how efficiently this can be done depends on many things, principally the type and size of dredger which is used; in any case it is done so with steeply increasing cost penalties.

If one has to attempt reclamation with essentially poor material, such as a mixture of fine sand, silt and clay, losses could rise to 80% or more and one would have to be rather desperate to attempt a marine reclamation on that basis.

Having got the right mix from the borrow, how, where and when does one test it? With reputable Contractors and experienced supervision, testing can be carried out visually and with very elementary "instant" sampling techniques on board the dredger, barge or ashore at the end of the delivery line. "Instant" sample techniques include fingers, handfuls and domestic buckets on a rope. Back-up sampling and testing is prudent and the methods are discussed in other papers. What do you do if the samples fail the test? Just the same as you do when concrete samples fail.....

The best place to test if the fill is up to specification is in the fill. This is rarely done, at least outside Hong Kong! Not least because it is slow, can hinder the progress of the work, and, as it is widely accepted that competently executed, marine fill makes first class reclamation, it is an unnecessary expense. In fact the author had never come across such a requirement before working here. Asked how it could be done, the only practical way seemed to be by vibro-coring, which is what has been done at Kwai Chung. Whilst marine filling is understandably regarded with respectful caution here, the author is curious to know now the traditional material is sampled and tested in the fill?

One has heard doubts about the degree of compaction in marine fill but again the author feels that this is trying to apply double standards. One does not expect to apply external compaction techniques to the traditional fill after placing, and indeed the author knows of no way it could be done. So one should not be concerned about marine sourced fill. This is perhaps more a question of conviction rather than scientific proof on the part of the author.

Compaction and settlement of the body of a good i.e. granular fill, is very rapid, perhaps not quite "instantaneous" as the contractors would have us believe, but for all practical purposes, settlement is 98 or 99% complete by the time the finished level is reached. Of course once the fill has risen above water level, conventional land based compaction techniques can be specified as is thought necessary. The real problem seems to be the prediction of the settlement of the underlying in-situ material and that is one which the author is happy to leave with his geotechnical colleagues. To assist them he can agree to specify the installation of settlement markers but with the cynical expectation that many will be lost and never found.

The actual physical boundaries of the fill can be specified with fair precision. If the natural or pre-dredged seabed is competent material it will be practical to define the starting level of the fill to within 30 cm.

If filling is to take place on soft material, then one must decide in advance how the "bottom" is to be defined, a fertile field for discussion, but it must be done before and written into the specification. If soft material is to be left after preliminary dredging to predetermined depths, then vertical tolerances of 1.0 m. are quite acceptable. Horizontal tolerances for dredging should be of the order 1.00 m whereas tolerances for dumping can be as high as 5.00 m depending on depth, method and material. After clean-up dredging, this can reasonably be reduced to 1.00 m and this can also apply to fill placed by pipeline or grab. Above water, one can apply typical "drywork" tolerances, but do not expect the dredger to meet them.

Geologists know better than the author the angles of repose of materials above and below water, and he would be very grateful for their support in persuading some civil engineers to stop specifying unattainably steep slopes. Given an attainable slope, marine fill can be placed or trimmed to it within a few degrees; however, with ordinary equipment, the vertical and horizontal tolerances still apply, so an absolutely straight line slope is not to be expected. In practice it is rarely required.

Finished levels above water can be achieved to within 10 cm and in fact conventional earthmoving plant will be used to do this. Below water one should consider if one needs a tolerance at all because it requires special techniques or equipment at appropriate expense, and for run-of-the-mill reclamation it is unnecessary.

Summary and conclusion

The author has tried to present very briefly some of the practical aspects of the dredging process which constrain the design and specification of marine reclamation. He is aware that it is a very sketchy review, full of voids. However, it is hoped that the background knowledge helps to explain to non-specialists the reasons for arriving at the various numbered specifics, and just as important, the other apparently quite imprecise "specifics". He repeats the warning given early in the Paper. Be very wary of transporting experience from one job to another or extracting figures and formulae from books and papers, especially this one!

When pressed for the "right" specification for a marine fill the author repeats ad nauseam all the ifs and buts, and finally gives:-

Ford's Favoured Fill

About : 80% in the sands fraction
15% in the silts & clays (but no more than 5% organic)
5% gravels or coarser

And stop worrying about shells!

References

- Bray, R.N. (1979). Dredging : A Handbook for Engineers. Edward Arnold Ltd, London.
British Standards Institution (In Preparation). Code of practice for Maritime works. British Standards Institution.

Dredging methods and materials for reclamation

B. Groothuizen

Van Oord International BV

SUMMARY A very outstanding feature of dredging is that the material to be dredged is under water and invisible. This in contrast to dry earth moving. Site investigation must bring some light in the darkness. All types of site investigation are possible of which bore hole probing is one of the most important methods. Soil samples thus obtained form the base for the classification of the material to be dredged. A proper knowledge of the subsoil is of vital importance for selecting the right equipment and to judge the suitability of the material to be dredged as fill material for reclamation.

This presentation starts with a brief review of the classification system widely used and promoted in the dredging world. After that a summary of various dredging methods is given, which is followed by some relevant aspects of reclamation. The presentation is concluded with some remarks on the cost price of dredging.

Within the context of this presentation it is impossible to go into much detail of every subject mentioned. Due to the wide spectre of very specialised areas of knowledge a choice has to be made.

Classification of soils and rocks to be dredged

A brief history

In October 1968 The Permanent International Association of Navigation Congresses (PIANC) set up an International Study Commission for the Classification of Soils to be dredged, in order to prepare a systematic method of describing various types of soils and rocks to be dredged with respect to dredging performance. At the time it was noted that :

"at any rate for the time being and also for the near future, dredging practise does not need a too detailed and very extensive system." However the commission was also aware of the fact that "the proposed classification system cannot be a static one but will only have to work for the next 8 to 10 years and will then have to be reviewed.

In October 1972 the report of the International Commission for the Classification of Soils to be dredged was published in PIANC bulletin no. 11, Vol I 1972.

Indeed it appeared that the proposed classification system could be regarded as a beginning of a discussion on this subject in the dredging industry. In November 1982 a draft revision of the report was circulated amongst the members of the International Association of Dredging Companies which was followed by a second revision in July 1983.

These revisions included amongst others more detail on the classification of rocks to be dredged. This was also reflected in the naming of the final report of the working group which was issued by PIANC in 1984 with the title : "Classification of Soils and Rocks to be dredged."

This report concentrates on an international approach to identification and classification of soils and rocks for dredging purposes. Frequent references are made to British Standards (B.S.) or American Standards (A.S.T.M.).

Classification

The civil engineering approach is followed in the distinction between soils and rocks. According to Terzaghi soil is a natural aggregate of mineral grains that can be separated by such gentle mechanical means as agitation in water. Rock on the other hand, is a natural aggregate of minerals connected by strong and permanent cohesive forces. This definition of soils and rocks differs from the corresponding geological terms of reference. To the geologist the term rock implies all the material which constitutes the earth's crust, regardless of the degree to which the mineral particles are bound together, whereas the term soil is applied only to that portion of the earth crust which is capable of supporting vegetation.

Soils

PIANC uses the following characteristics as a base for classification :

- grainsize/shape of the grains
- plasticity (cohesive versus non cohesive)
- strength and structural characteristics
- smell and colour
- for peats : extent of decomposition

According to the size of the individual grains and plastic nature the following main soil types can be distinguished :

<u>Soil type</u>	<u>Grainsize</u>			<u>Plastic nature</u>
boulders		> 200	mm	non cohesive
stones	200	- 60	mm	non cohesive
gravel	60	- 2	mm	non cohesive
sand	2	- 0,06	mm	non cohesive
silt	0,06	- 0,002	mm	non cohesive
slay	<	- 0,002	mm	cohesive
peat	variable			

Soil types always occur in combination. In describing the soil the main constituent is always indicated by a noun. Other constituents which were present in smaller quantities are indicated by adjectives.

For dredging purposes the following soil parameters are required some of which may either apply to sand, silts or clays.

- Particle size distribution
- Particle shape
- In situ density
- Specific gravity of the solid particles
- Compactness
- Permeability

- Natural moisture content
- Plastic and liquid limits
- Shear strength
- Lime content
- Organic content

These parameters are obtained by in situ and laboratory testing. Most of these tests are described in B.S. 1377. The PIANC classification provides an extensive reference as to what tests are required and what National Standard is applicable.

Rocks

The system of the classification of rock adopted by PIANC is based on common geological practise i.e. the classification is according to the way of coming into existence. Hence the following rock categories are distinguished.

- Igneous rocks
- Metamorphic rocks
- Sedimentary rocks

Within these categories rocks are classified according to grain size.

In addition to the rock type an indication should be given of the following characteristics :

- colour
- grainsize and texture
- strength
- bedding, jointing, fracturing, discontinuities including orientation etc
- degree of weathering

Of these parameters, the degree of weathering, the rock strength and the fracture state are most important for dredging.

Rock strength is scaled according to the following table.

<u>Term</u>	<u>Compressive strength (MN/m²)</u>
Very weak	less than 1.25
Weak	1.25 - 5
Moderately weak	5 - 12.5
Moderately strong	12.5 - 50
Strong	50 - 100
Very strong	100 - 200
Extremely strong	greater than 200

For dredging the respective strength ranges are rather large. Therefore it is very important that when providing descriptive terms, the test results should also be provided.

The fractured state of rock cores is indicated by means of the total core recovery, the solid core recovery, fracture log and Rock Quality Designation (R.Q.D.).

Total core recovery :

This is the length of the total amount of core recovered expressed as a percentage of the length of core run.

Solid core recovery :

This is the length of core recovered as solid cylinders expressed as a percentage of the length of core run.

Fracture log :

This is the number of natural fractures present over an arbitrary length, for instance per meter of core run.

Rock Quality Designation (R.Q.D.) :

This is the sum of the length of all core pieces (100 mm or longer), measure along the centre line of the core, expressed as a percentage of core drilled.

On the bore hole log the drill method and size of drill employed must be stated.

In addition colour photographs of rock cores are a very important aid.

Choice of equipment

In this presentation emphasis is placed on the nature of the subsoil with respect to dredging feasibility. However the subsoil characteristics are not the only determining factor for the choice of the most suitable dredging equipment at the required location.

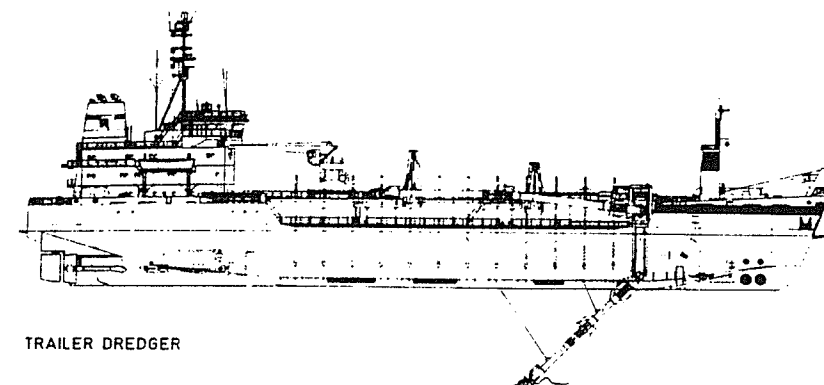
Other considerations are :

- wind, wave and current conditions
- water depth at which the dredging must be performed
- dredge volume
- use of the dredged material i.e. disposal or reclamation
- time programme of the project
- the location of the site

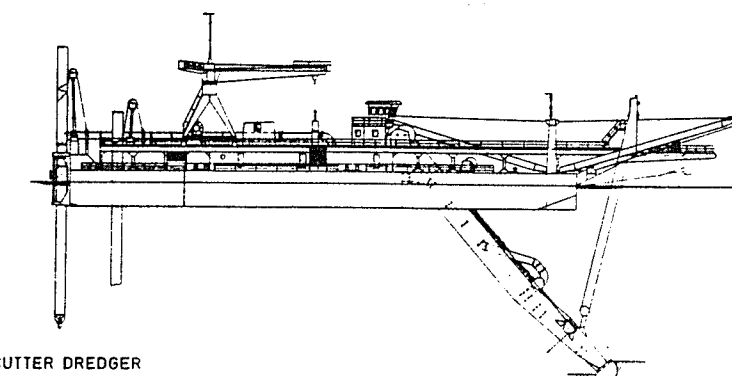
In general it can be stated, that except for the trailing suction hopper dredge all dredge equipment is to a more or lesser degree sensitive to wave action. The relevant parameters being the significant wave height (H_s) and the wave period (T). It should be stated that for waves exceeding 2,5 to 3 m also the trailing suction hopper dredge meets her limitations.

The feasibility of a certain piece of dredging equipment depends also on the size and strength of the construction and the installed capacity. Due to the great variation of all these factors involved, an indication of the feasibility of certain dredging equipment with respect to soil conditions can only be a very rough approximation. This consideration must be kept in mind when reading table 1 which is an abstract of a table originally published in the 1972 report on the classification of soils to be dredged.

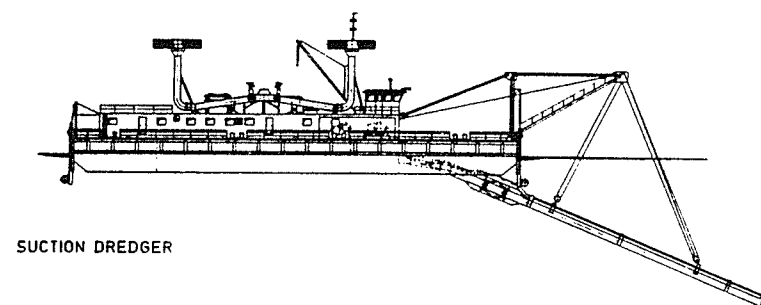
In order to form one self a picture as to what type of equipment we talk about, the pieces of dredging equipment mentioned in this table are shown schematically on figure 1.



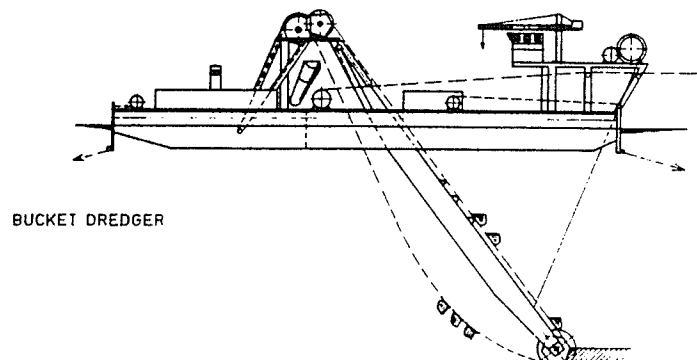
TRAILER DREDGER



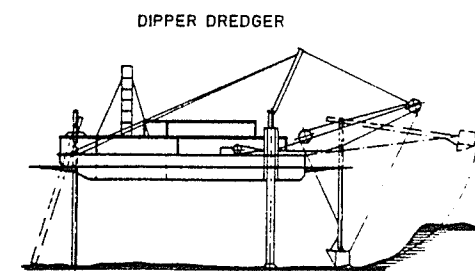
CUTTER DREDGER



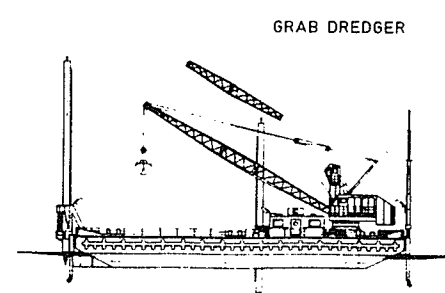
SUCTION DREDGER



BUCKET DREDGER



DIPPER DREDGER



GRAB DREDGER

Figure 1. Different types of dredger

To illustrate the point that each type of subsoil required its own approach in selecting the right dredging tool, a specimen is shown of a cutter head for dredging soft soil, Plate 1 and hard soil Plate 2.

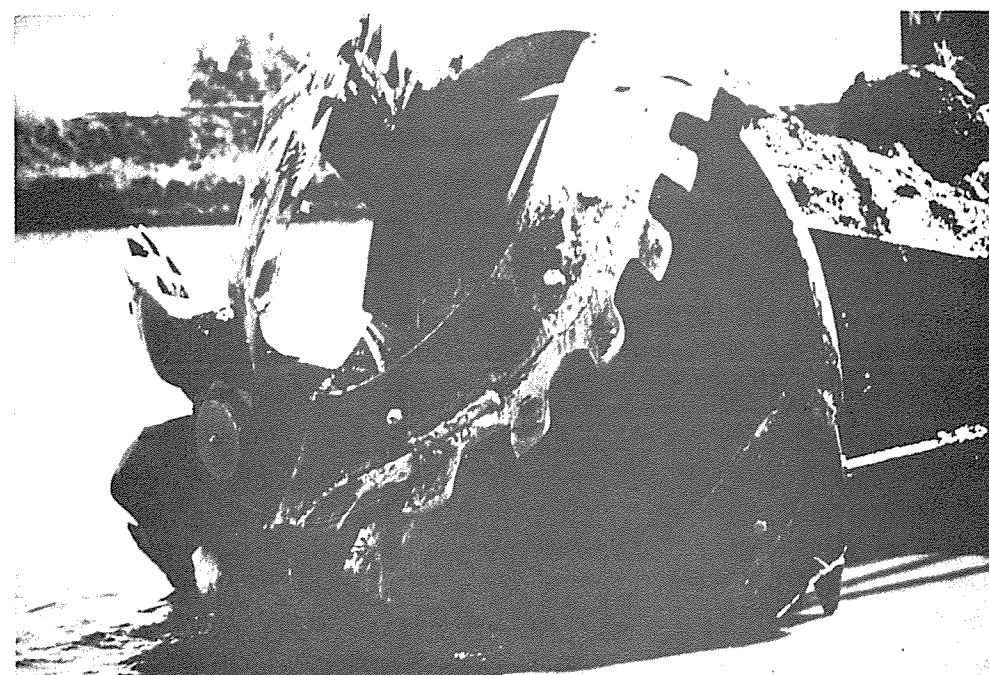


Plate 1. Cutter head for soft soil

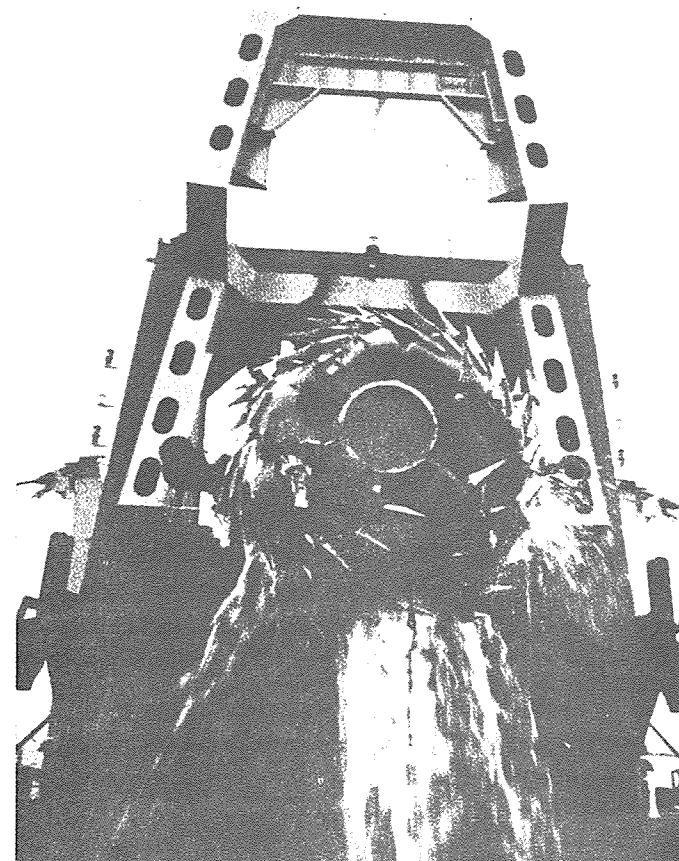


Plate 2. Cutter head for hard soil

Table 1 Dredgeability of soils and rocks

Rock/Soil type	Excavation Characteristics					
	Dipper Dredger (1)	Bucket Dredger	Suction Dredger (2)	Cutter Dredger (3)	Trailer Dredger (4)	Grab Dredger
Rock ** Igneous	NA	NA	NA	NA	NA	NA
Metamorphic	NA	NA	NA	NA	NA	NA
Sedimentary	in soft rock +	in soft rock +	NA	in soft rock + to x	NA	in soft rock ++
Boulders	x	+	NA	NA	NA	+
Cobbles	x	x	+	+	+	x
Gravel	0	x	+ to x	x	+ to x	x
Sandy gravel	0	x to 0	x	x to 0	x to 0	x to 0
Sand	0	0	0	0	0	0
Cemented fine sand	x	x	NA	x to 0	+	+
Silt	NA	0	+ to x	0	x to 0	x
Firm or stiff gravelly or sandy clays	x	x to 0	NA	+ to x	NA	+ to x
Soft silty clays	NA	x to 0	NA	0	x	0
Firm or stiff silty clays	x to 0	0	NA	x to 0	+ to x	x
Peats	NA	0	NA	0	X	0

Legend excavation characteristics :

0 Easy
x Fair
+ Difficult

Note :

** The weathering of rock alters form and strength considerably and may allow dredging without blasting.

(1) See Plates 3 and 4 (3) See Plate 6
(2) See Plates 5 (4) See Plates 7 and 8

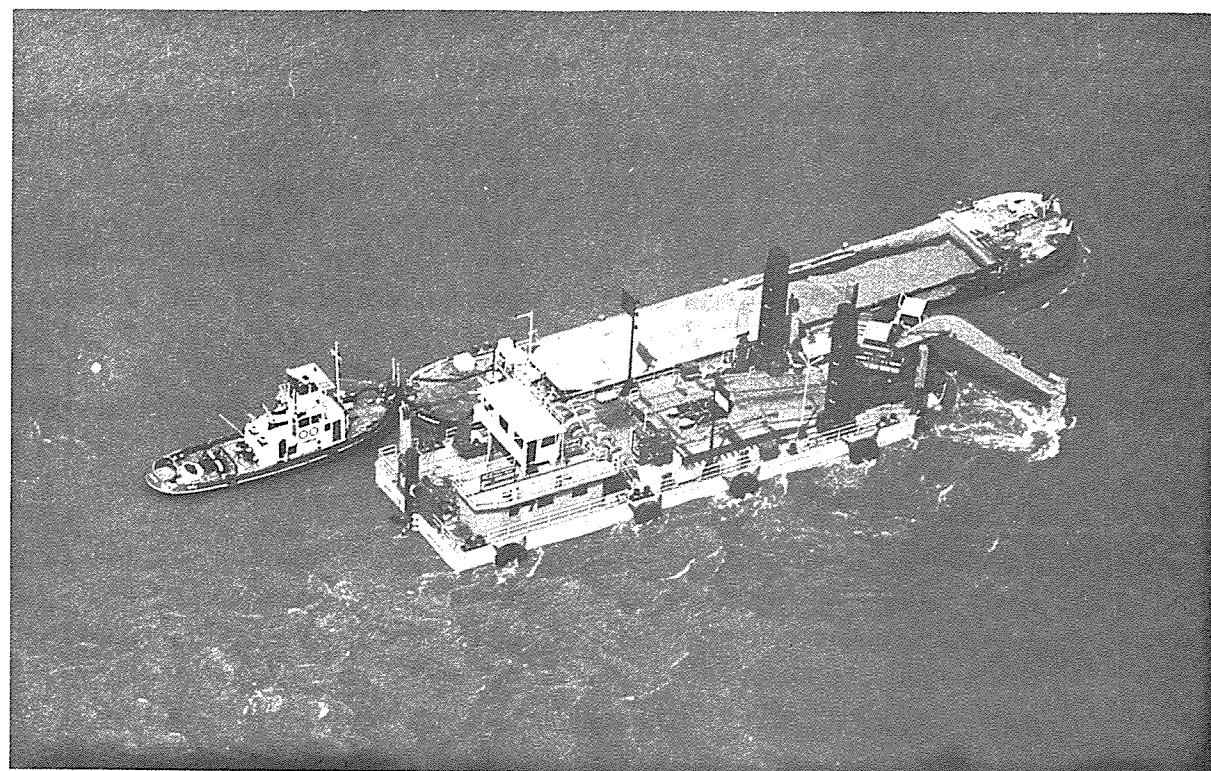


Plate 3. Dipperdredger

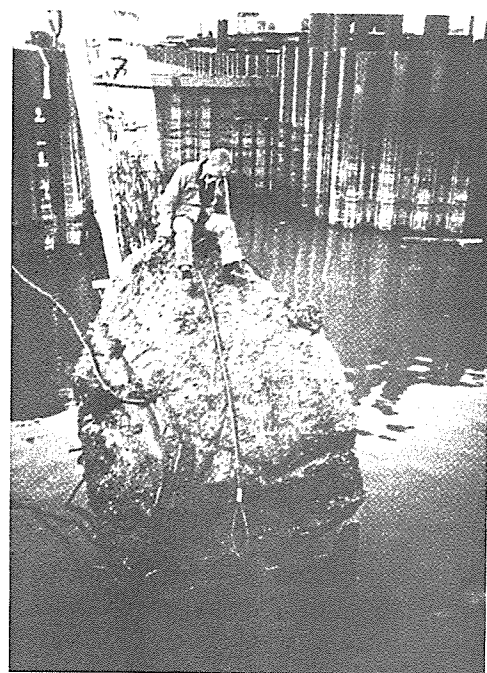


Plate 4. Dredging "Boulders"

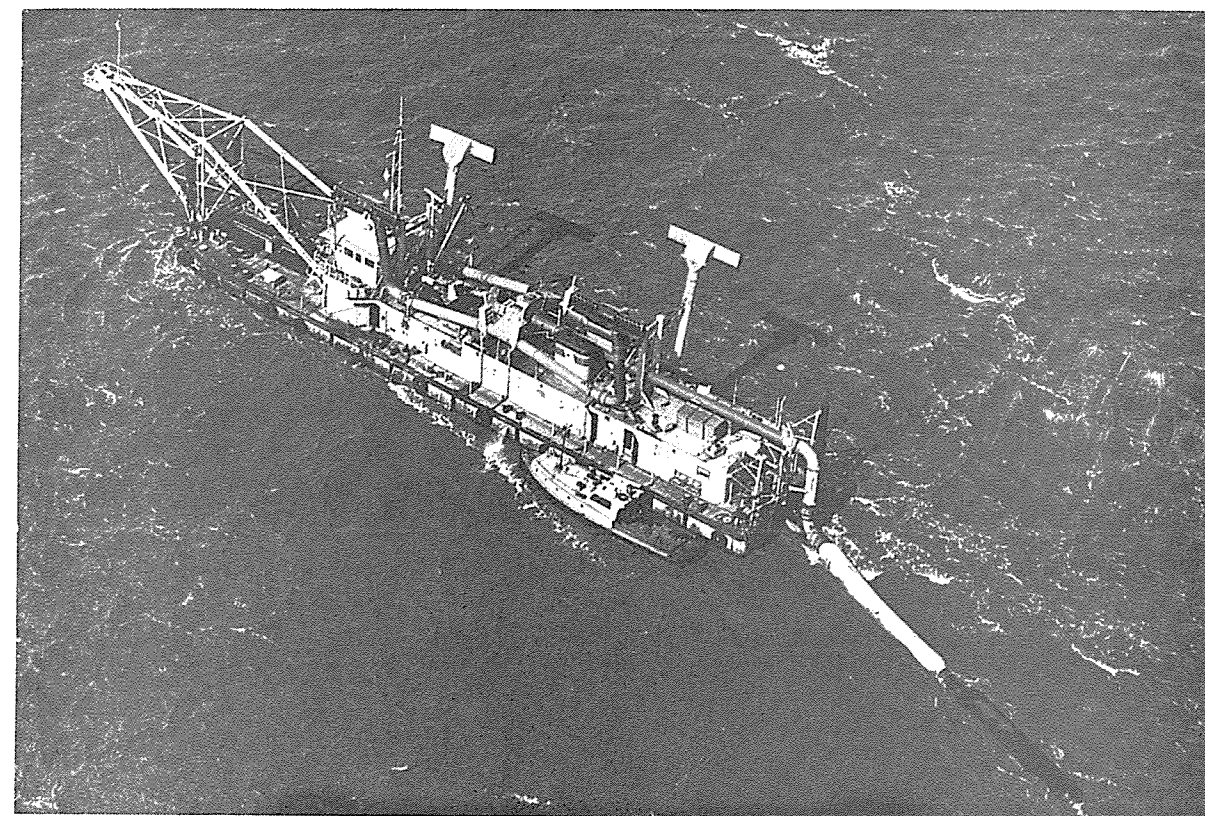


Plate 5. Suction dredger

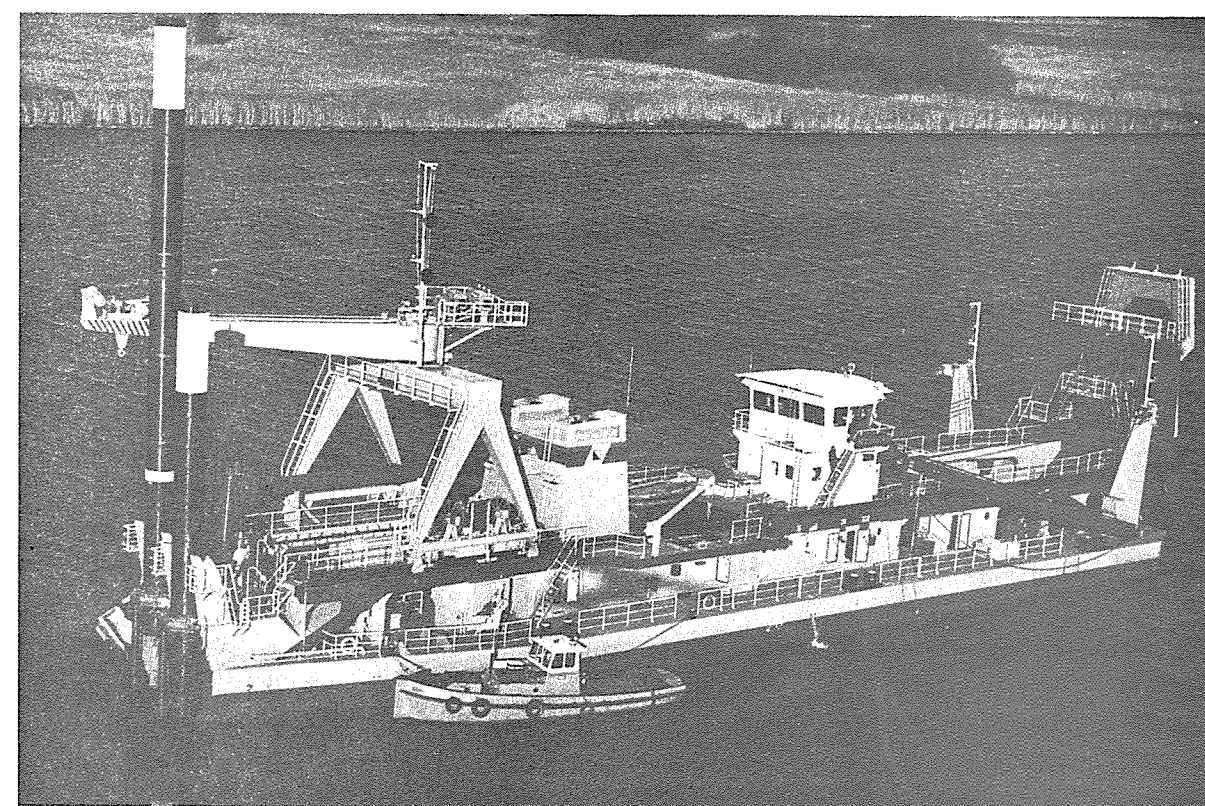


Plate 6. Cutter dredger

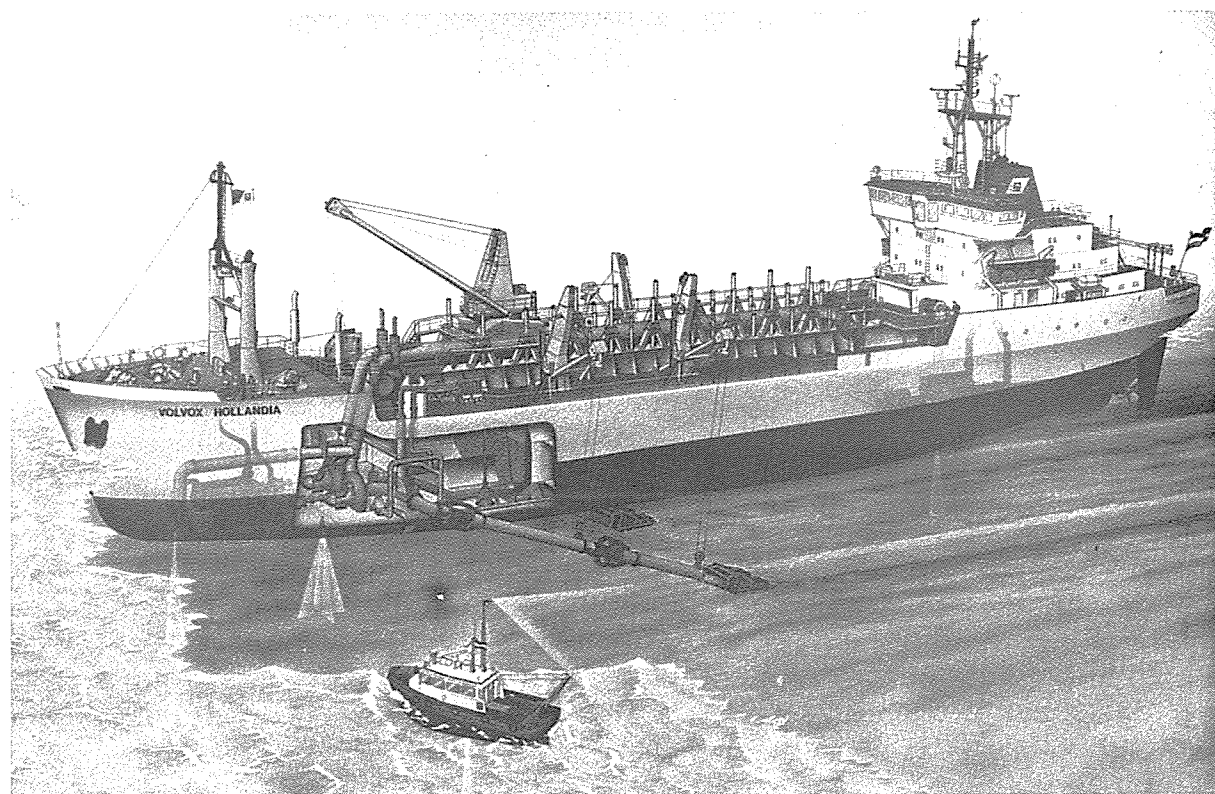


Plate 7. Trailing suction hopper dredger

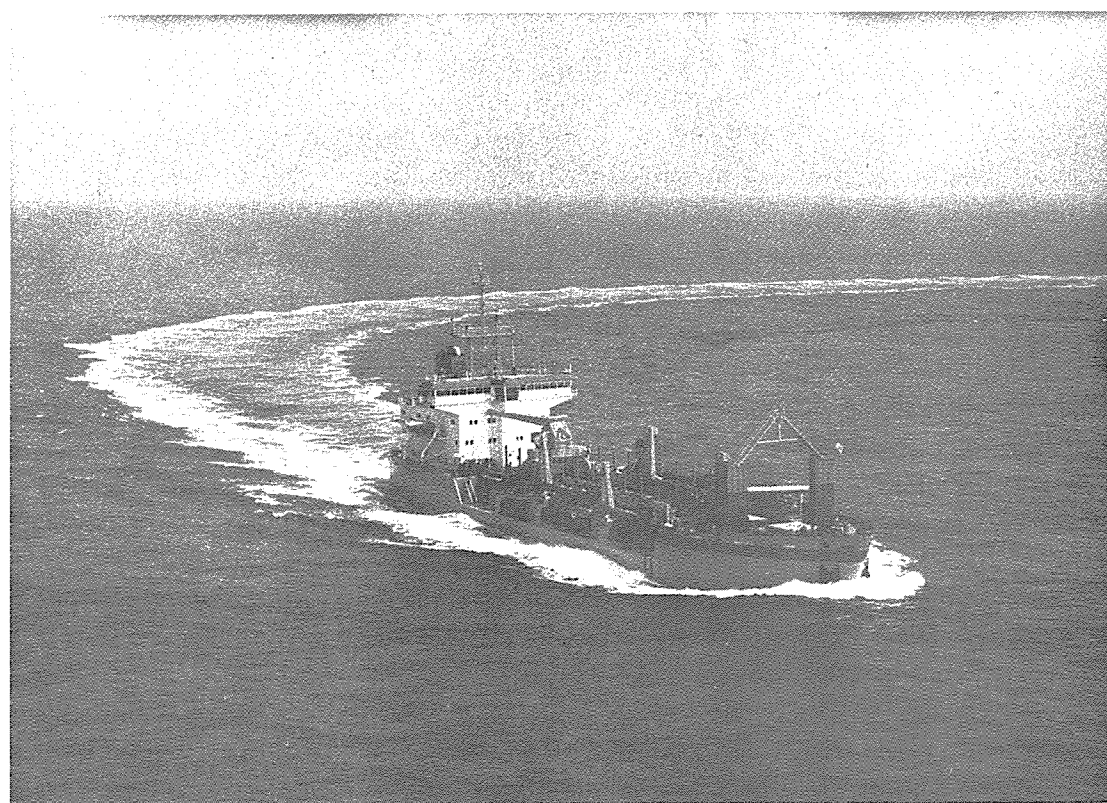


Plate 8. Volvox Delta 8000 m3 capacity Trailing suction hopper dredger

Transport of hydraulic fill

The transport of the dredged material from the dredged area to the full or dump area can be done in various ways. This will be explained using the scheme of figure 2. On this scheme three modes of the dredging process are considered :

- The dredging itself.
- The transport of the dredged material.
- The placing of the dredged material.

When using a dipper dredger, bucket dredger or grab dredger, the dredged material can either be placed directly into the dump area or transported to the dump site by using barges (hopper-split- or flat deck barges). If the material cannot be dumped directly, the barges are unloaded by means of a barge unloading dredge which subsequently pumps the fill via a pipeline into a reclamation area.

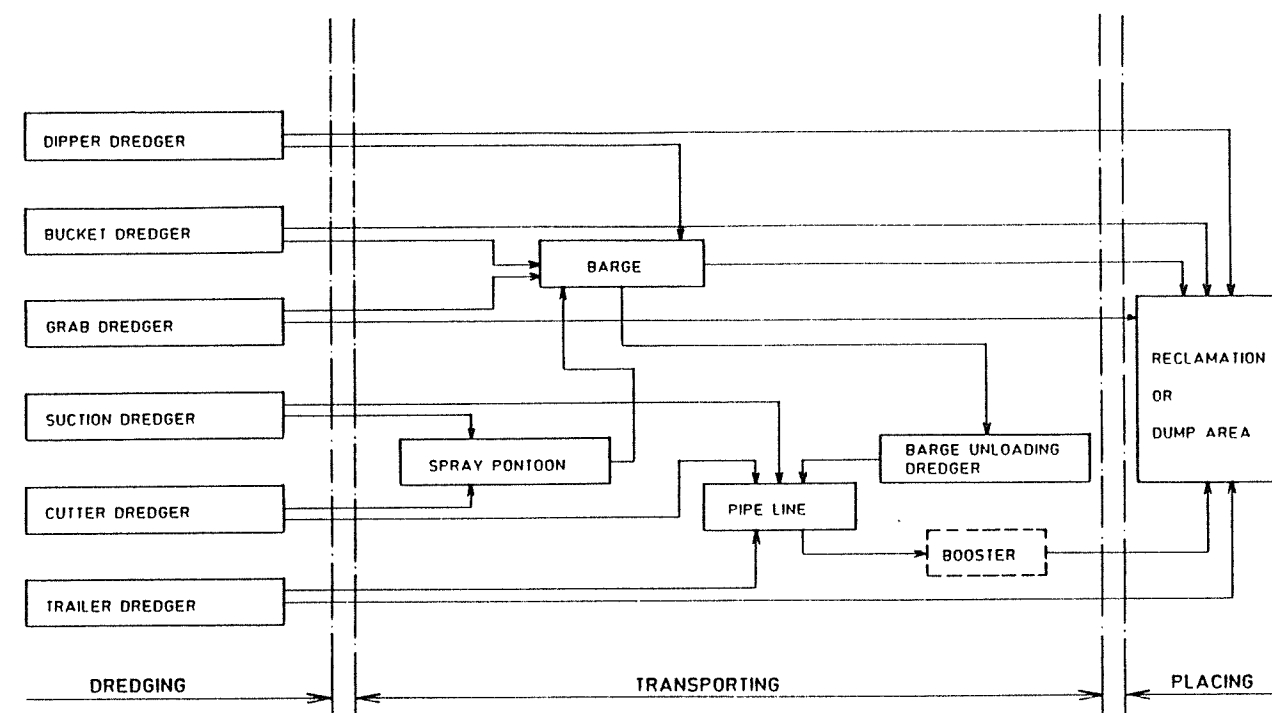


Figure 2 Dredging process

When using a suction dredger or cutter dredger it is most common that the hydraulic fill is directly pumped into the reclamation area via a pipeline. In case a transport across water this pipeline can be a floating pipeline or a sunken pipeline, Plate 9. In case of long distances booster stations have to be used to provide the extra required pumping pressure. Depending on the transport distance across the water, transport can also be carried out using barges. Via a spray facility the barges are filled alongside the dredger, Plate 10. In case the dredged material cannot be dumped directly, again a barge suction dredge is used for discharging of the barge and pumping the material into the reclamation area via a pipeline.

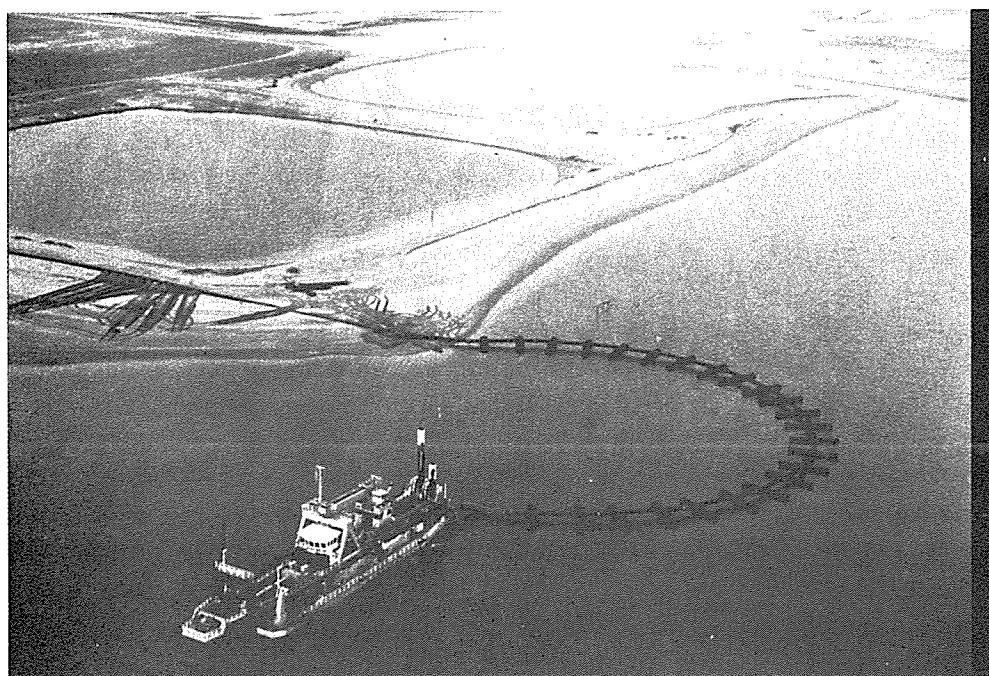


Plate 9. Cutterdredge at reclamation site

When a trailing suction hopper dredge is used the dredged material is normally transported directly to the dump site by the hopper dredge itself. This applies to most cases. However when the dredged material is to be used for reclamation, various systems are possible.

- The hopper dredge discharges herself via a (floating) pipeline. similar to that attached to the cutterdredge in Plate 9.
- The dredged material is directly rainbowed into the fill area i.e. jetting the fill through the air across distances of up to 150m, Plate 11.
- Often a combination of the described systems is also used :
The hopper dredge discharges herself in a special allocated dumping pit from where the material is dredged again by a suction dredge and transported to the reclamation area via a pipeline and/or barges as the case may be.

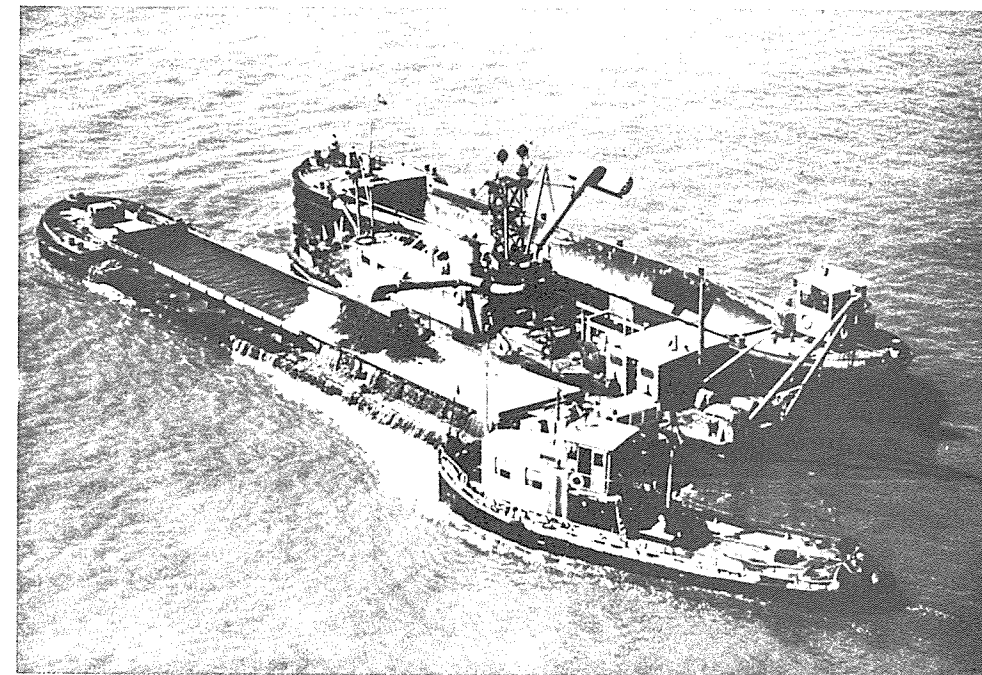


Plate 10. Barge loading operation using a spray system

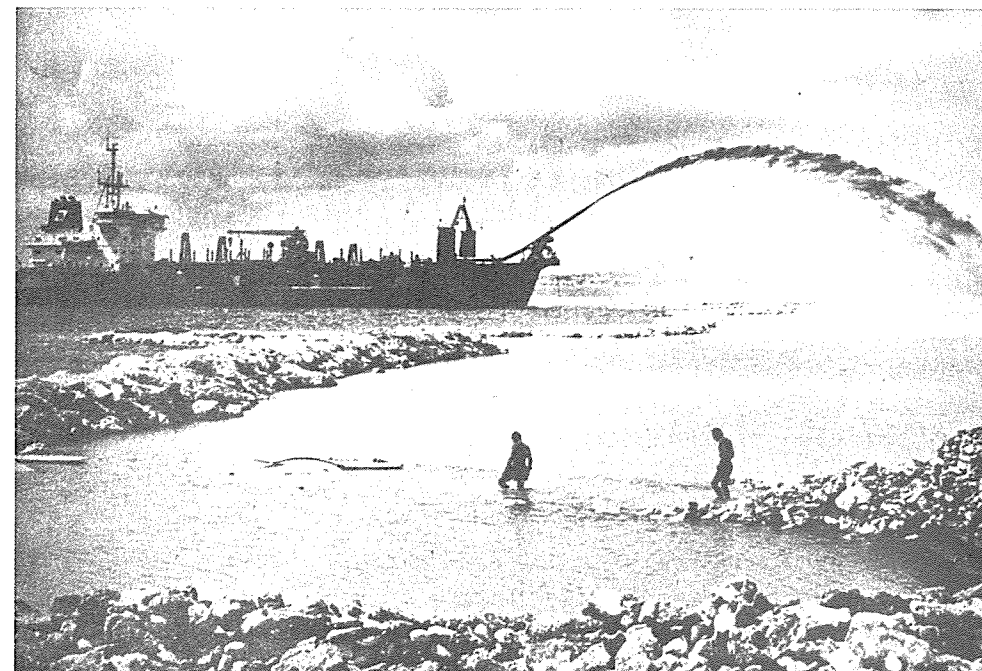


Plate 11. Trailing hopper dredge "rainbows" sand into reclamation area

When considering the dredging process and especially the transporting system, weekly production rates of up to 250.000 m³ or even 400.000 m³ are not uncommon. Often the sand winning is out at sea or some remote place in a river away from populated areas. The pipeline systems and barges, as the case may be, take care of a very quick and reliable transport system with a very high capacity. Apart from a very competitive cost level this aspect should be born in mind if the alternative is a dry earth moving reclamation operation.

Reclamation

The client usually formulates the following three conditions on the quality of the reclamation.

1. The level of reclamation must be realised within certain pre-set variations say + or -0,20 m.
2. The percentage of fines must not exceed say 15% i.e. material having a grainsize smaller than 0,06 mm.
3. The compaction of the fill must meet certain standards.

Settlement

In order to realise condition 1 information must be available on the settlement characteristics of the subsoil underneath the area to be reclaimed. If this is marine clay settlement can be considerable both during the construction period and after completion. As a maintenance period of at least one year is usually enclosed in the contract, a major portion of the extra volume required with respect to settlement has to be taken into account by the contractor.

Limitations of fines

The condition to allow only a limited volume of fines in the reclamation area is dictated by the fact that sufficient drainage must be maintained through the fill when a load is applied, whatever that load may be. Also settlement of the fill itself can be disregarded if not too many fines are included. When using hydraulic fill for reclamation, the input of fines must be controlled by the dredging process. Selective dredging must be applied when in the dredge area both coarse and fine material occurs. Also the fines can be washed out by overflowing when pumping the dredged material into a barge. A great disadvantage is that after a while the same winning area is covered with a layer of fine material.

In case it is difficult to find suitable material for filling, ways must be found to employ the fine materials including clay encountered in the dredge area. This can be done by placing layers of coarse material and layers of fine material alternately on top of each other during the fill process. The idea being that the layers of coarse material take care of horizontal transport of excess water. In order to reduce the settlement of the intermediate clay layers care must be taken that these are placed

with the highest possible densities. In selecting the fill method it must be realised that the fill area will not be accessible during the fill process. Figure 3 shows a work method which copes with these two considerations.

The sand is placed in very thin layers on top of the clay by using the rainbow method. After this clay is placed on top through a diffuser near the bottom by using a displacement pump. A high density of this clay is obtained by using a grab dredge for excavation. Due to the inaccessibility of the fill area all placing must be performed by means of floating equipment. In order to make this possible at higher levels the water level must be raised.

When applying clayey layers in between coarse layers it may be necessary to provide a temporary overload of fill in order to speed up consolidation.

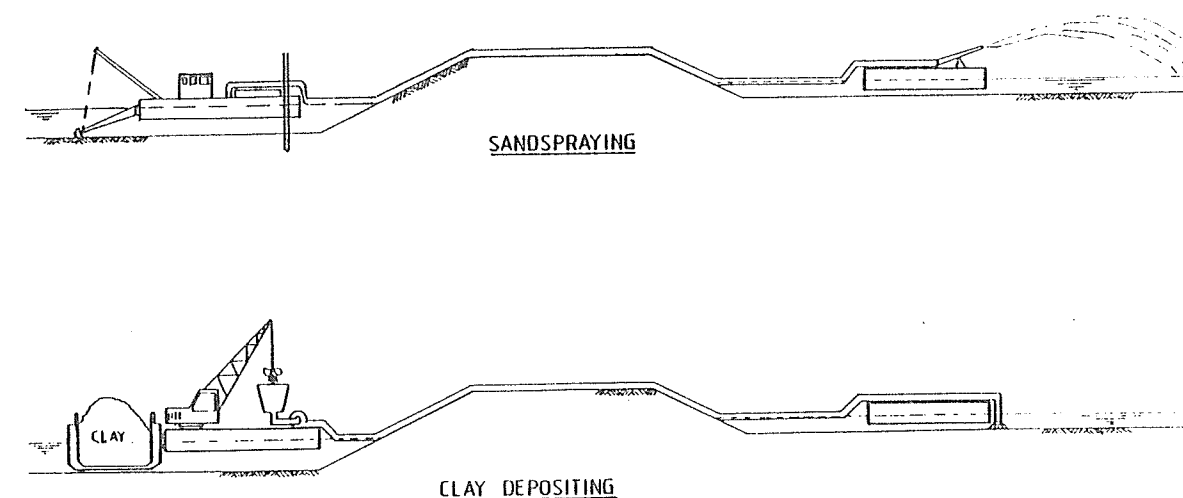


Figure 3 Example of work method for placing sand and clay layers in reclamation area

Compaction

In order to obtain the required degree of compaction of earth works it is common practise when executing a dry earth moving job to place the fill in layers not exceeding say 0,30 m at the time, to maintain the optimum moisture content for which a maximum density is reached and to compact each layer with specially devised compaction machines. The whole process is closely monitored by carrying out Proctor tests and to measure the density of the fill in the field.

This is all very impractical when carrying out a reclamation job using hydraulic fill because of the following reasons :

- Due to the nature of the filling process - large quantities in a continuous operation - the fill is usually raised above water in one step.. If layers are applied, the thickness usually amounts to 2 or 3 meters at least, whereas the front moves forward in terraces. The dimensions of these may sometimes be dictated by soil mechanical conditions.
- Because of the use of water as a transport medium there is no subtle control of the moisture content as required for dry earth moving.

Despite these circumstances it appears that high densities are reached, which is for a great deal due to the use of earth moving equipment on the fill area to control the sand/water flow.

Dredging Costs

From what has been said of the dredging process it is clear that due to the great variation of all the factors involved the dredging costs from project to project may vary considerably as each project has its own typical approach. However to give an indication as to what cost level for dredging works one should think of, prices per m³ may vary between 10 and 30 HK \$ for soil which can be dredged relatively easy. These prices may go up to 200 HK \$ and more if for instance stiff boulder clay has to be dredged.

In order to give an understanding as to what extent the production rate may influence the total price level of a dredging/reclamation project a summary is given of the cost items involved in table 2.

Table 2 Cost items of a dredging/reclamation project

<u>Cost items</u>	<u>% of costs</u>
- Interest and Depreciation	70%
- Insurances	
- Fuel and Lubricants	
- Maintenance, Wear and Tear	
- Reclamation Attendance	20%
- Pipelines	
- Site Supervisor and Survey	10%
	100%

Only very approximate percentages of the cost figures can be given. For instance the wear and tear costs may vary up to a factor 4 depending on the type of subsoil.

In general it can be stated that a wrong estimate of the expected production rates of the dredge equipment will influence the dredge costs at least up to 90%. This again underlines the importance of a good soil investigation presented in a common technical language.

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Marine investigation for sands

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SUMMARY This paper reviews the differing site investigation requirements of the Engineer and the Dredging Contractor and emphasises the need for the involvement of the Dredging Contractor at various stages of the investigation.

The main site investigation techniques used for marine sand exploration are briefly reviewed and reference is made to recent trends in Hong Kong relating to the use of vibrocoring.

Introduction

The approach to a marine site investigation for granular sources of fill material is different in many respects to a conventional site investigation. Structures do not have to be designed to sit in the area being investigated and although stability of the excavation is a consideration, it may be desirable to have an unstable excavation to ensure the free flow of material into the dredge pipe, whilst maintaining the stability of any overburden deposits.

With the increasing scale of reclamation projects in Hong Kong and the desirability of completing the reclamation work over a reasonably short time scale, large international Dredging Contractors are converging on Hong Kong and have recently been very successful in winning reclamation work using marine sources of fill. Recognition has to be given to the fact that international Dredging Contractors usually know far more about dredging than either the Engineer or the Employer. If they are not given the site investigation information they require they will frequently resort to carrying out additional site investigation works themselves.

This paper examines the site investigation requirements of the Consultant or the Engineer and those of the Dredging Contractor. Whilst there is some common ground between the two, there are differences in their respective requirements which, if not addressed, can cause problems. To the Dredging Contractor his business is as much an art as a science. He relies heavily upon experience and likes to be able to see and feel the materials he is dealing with. The Engineer would probably admit to a more scientific approach. However, both the Engineer and the Dredging Contractor share the common aim of economically exploiting the marine sand resources, although there are differences in emphasis; the Engineer looks for a controlled exploitation of suitable materials that minimises the impact on the local environment, whilst the Dredging Contractor, by necessity, is interested in a cost effective method of extraction and compliance with fill specifications at the other end.

A review of the marine site investigation techniques currently being used in Hong Kong clearly illustrates the emergence of vibrocoring as an increasingly widely used method for obtaining near continuous samples over considerable depths.

Planning of site investigations

There are a number of possible ways in which a site investigation programme for marine sources of fill may be organised. These may range from designating areas for borrowing and allowing the prospective Dredging Contractors to carry out all the investigations they consider necessary to enable them to tender for the work and comply with the specifications, through to carrying out all the site investigation work before tendering the project and presenting the Dredging Tenderers with the results at the tender stage. There are of course numerous combinations and permutations of the arrangements which may, for example, entail preliminary site investigation under the direction of the Engineer to establish the areas to be designated for borrowing and then the carrying out of further more detailed, site investigation in consultation with the prospective tenderers.

The approach adopted will have a significant bearing on the scope and objectives of respective site investigations. In some parts of Europe for example, where abundant sources of suitable marine fill are known to exist, it is not uncommon for the Engineer to designate the area for borrowing and for the Dredging Tenderers to implement their own investigations. However problems are likely to occur with this approach if the reserves are later proven to be insufficient to meet the contract demands.

In Hong Kong the experience of large scale borrowing for marine sources of fill is limited. The two largest and most recent are for Tin Shui Wai (Dutton, 1987) and Terminal 6 at Kwai Chung (Wragge-Morley, 1988). In both cases the shortlisted Dredging Tenderers were invited to become involved in the later phases of the site investigations.

Whatever the approach it is clear there is the need for investigation of marine fill to be carefully thought out. In common with many land investigations the formulation of a systematic grid of boreholes is not necessarily the most cost effective way to organise an investigation. Marine sediments, particularly in the nearshore context, tend to be highly variable and any worthwhile investigation needs to take account of the local geological environment. Another implication of this is the need for flexibility and the site investigation should be adapted as it progresses to respond to the available information. Phased investigations are preferred, allowing an initial preliminary evaluation and subsequent detailed studies to be concentrated in potentially promising areas.

There is also little doubt that clients will ultimately obtain best value for money by the close co-operation of the Dredging Contractor and the Engineer, and indeed it has become the practice in Hong Kong to encourage the participation of prequalified Dredging Contractors at various stages of the investigation.

The Engineer's requirements

In designing and implementing a marine site investigation for fill material, the Engineer is usually primarily interested in establishing the quantities and quality of the source. It should be appreciated that the quantity of fill which an area will yield depends not only on the geological boundaries of the deposit, but upon the method of dredging selected. In addition, a substantial reduction in volume may result from the exclusion of fines required to meet the placed fill specification.

The concept of quality for fill materials of marine origin relates both to the integrity of the fill material (i.e. how its engineering properties may be affected by the presence of, for example, shell and organic remains) and to the grading of the deposit, especially its fines content. Both these factors influence the engineering characteristics of the placed fill and the behaviour during extraction. In environmentally sensitive areas, particularly near fishing grounds and oyster beds, large volumes of silt and clay cannot be released into the water. Fill sources with acceptably low limits of fines may therefore have to be located.

It is also important for the Engineer to be able to assess variations in quality throughout the deposit, often controlled by the geological history and local stratigraphy. Channel deposits can be particularly variable, showing both significant vertical and lateral inhomogeneity, and it is relevant for the Engineer to establish the distribution and continuity of the main sand horizons and any overlying materials.

The Engineer is also interested in the long term behaviour of the placed fill and thus needs to be able to assess the engineering characteristics of the source material. Clearly the available methods of winning the fill result in complete disturbance of the deposit, so unlike many conventional investigations the Engineer is not primarily concerned with obtaining undisturbed samples. Rather he needs to recover samples exhibiting a minimum loss of fines and the emphasis is therefore on obtaining representative samples.

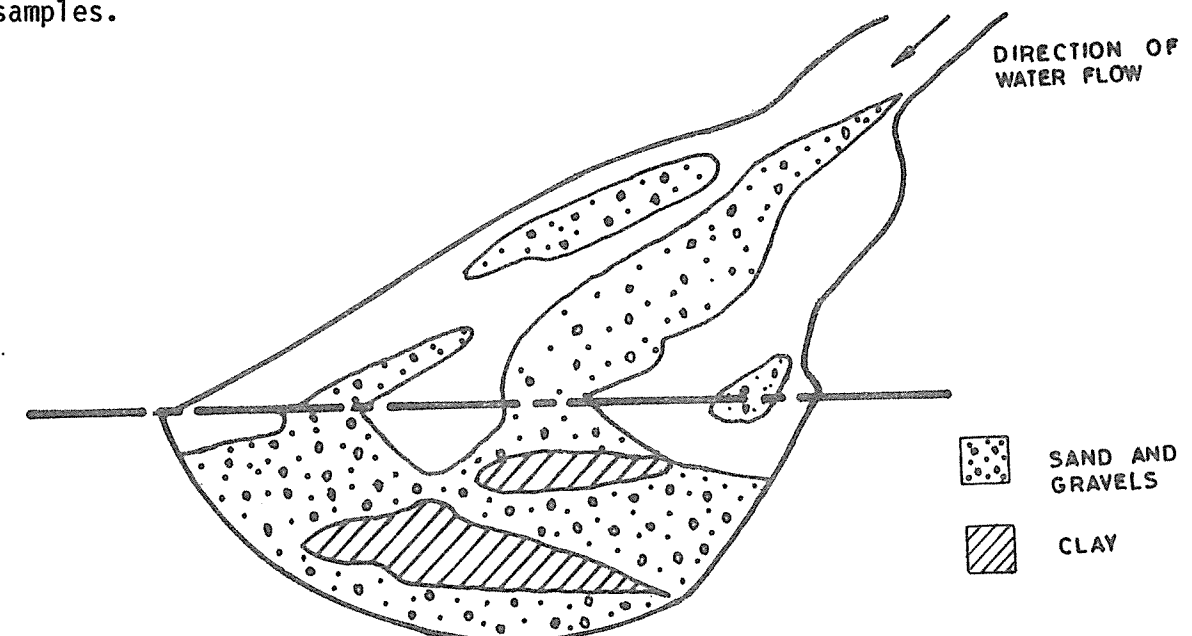


Figure 1 - Inhomogeneous channel deposits

The Dredging Contractor's requirements

The Dredging Contractor is usually concerned not only with establishing that a viable sand deposit of sufficient volume is present, but with the dredgeability of the deposit. Consideration has to be given as to how the material will be won, transported and placed and a number of different techniques exist. The recent dredging for Container Terminal 6 (Wragge-Morley 1988) used the suction hopper dredger. The material is sucked into the body of the dredger with a large volume of water, which is subsequently displaced by the incoming solids. Modern suction dredgers are able to control the fines content of sand fill by flushing out fines from the sand, as it is pumped into the hopper. This generates very turbid waters with a high fines content, which may or may not pose environmental problems.

Thus, the Dredging Contractor needs a knowledge of the following points:-

- (a) In situ material characteristics
 - density, compactness
 - grading and percentage fines
 - degree of cementation
 - in situ pore pressures
 - abrasiveness of deposit
- (b) Structure of deposit
 - variations in material properties
 - thickness and continuity of layers
 - depth and type of any overburden
 - size of area and distribution of sand horizons
- (c) Seafloor characteristics
 - relief of sea bed
 - current direction and velocity
 - presence of submarine service conduits
 - water depths and tidal variations
- (d) Weather conditions
- (e) Specification and tolerance requirements
(to be provided by the Engineer)

A knowledge of the above items allows the Contractor to plan his extraction strategy, including selection of the most suitable and economic dredging method.

One key aspect especially for the suction dredging Contractor is to assess the wear and tear implications of the deposit on the dredging equipment. Excessive wear and tear can occur in very angular deposits as well as in very dense and cemented materials. Damage can also occur to dredging equipment as a direct result of slope instability and often the Contractor needs to strike a balance between encouraging the free flow of material into the suction pipe and avoiding submarine slips that damage equipment and hamper his operations. There have been several examples in Malaysia where submarine slides have occurred, resulting in bucket dredgers being tipped over and bucket conveyors seriously twisted. These slips originate either due to oversteep cut slopes or as a result of the dumping of large volumes of fines

behind the dredge, resulting in high in situ pore pressures in an effectively undrained condition. Thus, whilst geotechnical stability is not of prime importance, an awareness of the potential for slips is relevant, particularly in shallow waters. Another offshoot of such slips is the contamination of good quality reserves by tailings with a high fines content possibly necessitating an expensive double handling exercise.

In this context the Dredging Contractor may also require a number of undisturbed samples of both overburden and the potential source material. These samples are invaluable in allowing the Dredging Contractor to properly assess the dredgeability aspects of the deposit and to design an economic dredging plan.

Review of site investigation techniques

Investigations for marine sands must therefore aim to provide data required by both the Engineer and the Dredging Contractor on the distribution, thickness, dredgeability and quality of potential fill materials. In addition data on the bathymetry of the sea floor, as well as the characteristics of any overburden are required.

Most investigations include geophysical investigations coupled with grid sampling. The techniques available for site investigations around Hong Kong have traditionally adopted onshore systems deployed on floating vessels or jack-up rigs (Blacker and Seaman, 1985). In general the emphasis is on low cost investigation methods at the expense of quality as the costs associated with carrying out work over water can increase very significantly with increasing water depths.

It is important to appreciate the Dredging Contractors rely heavily upon their familiarity with testing and, to a lesser degree, sampling techniques to enable them to interpret the results obtained. As in many cases they are not looking for specific engineering parameters but wish to relate their experiences with other projects to the project under consideration. The use of techniques with which Dredging Contractors are familiar can therefore be very important. For example, two of the commonest techniques for assessing in situ density and material variability with which the Dredging Contractors are very familiar are the SPT and the CPT.

Typical marine site investigation

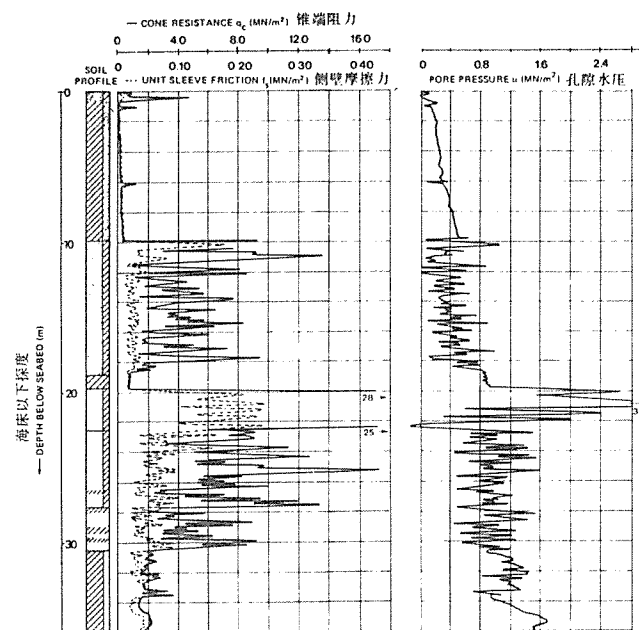
The scope of a typical marine site investigation for fill material would be as follows:

- Bathymetric surveys
 - Echo sounders
 - Side scan sonars
- Geophysical surveys
 - Seismic reflection (boomer)
 - Acoustic surveys (pinger)

- Sampling
 - Grab samples (sea floor)
 - Vibrocoring
 - Driven samples
 - Push samples
 - Gravity samples
 - Mazier samples
- In situ testing
 - Mechanical and Electrical Cones] Cone Penetration
 - Piezocone] Testing (C.P.T.)
 - Standard Penetration Testing - S.P.T.
- Laboratory testing
 - Particle size distribution (wet sieving)
 - Atterberg limits

Depending on the presence or otherwise of clayey overburden materials, in addition to the above in situ shear strength testing using either CPT or vanes coupled with laboratory testing on undisturbed samples would also be undertaken.

Descriptions of the geophysical techniques used are given elsewhere (Ridley Thomas et al, 1988). The in situ testing and sampling techniques are in most cases well known and are not described here (Brenner and Phillipson, 1979).



Typical
Cone
Penetration
Test Result

(Hatched soil
= clay
unhatched =
sand)

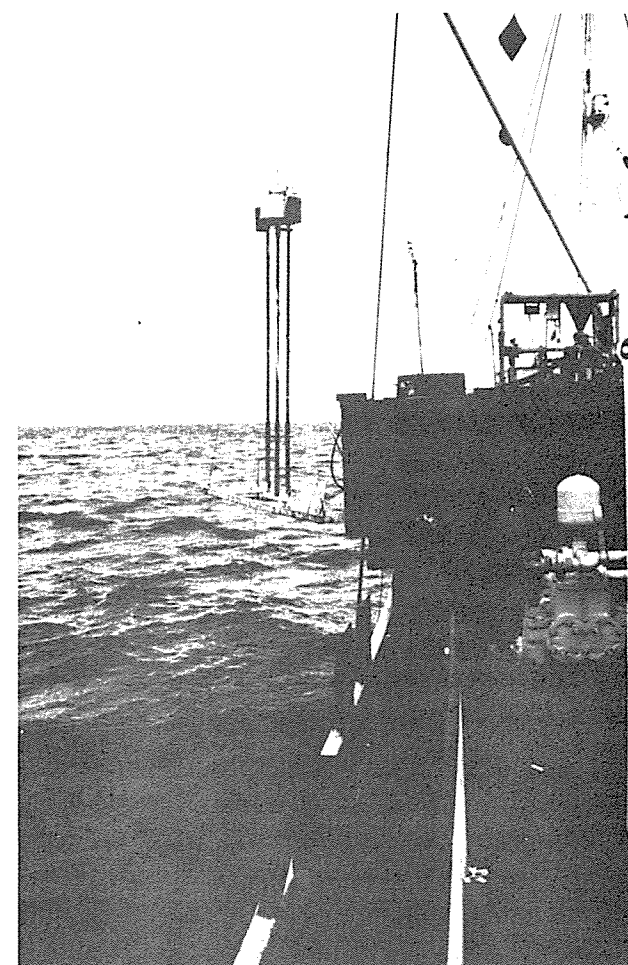
Vibrocoring

The increasingly widespread use of vibrocoring in Hong Kong over the past twelve months has marked a watershed in that a technique that does not have its origins in onshore site investigations has become widely accepted.

Worldwide, vibrocoring is one of the commonest investigation techniques used over water and comprises a system whereby a sample tube typically 6m in length is vibrated into soft or loose sediment. The sample tube and vibrating head are normally mounted on a submersible frame which is lowered over the side of the boat onto the seabed. However a recently developed Hong Kong technique is more flexible because it dispenses with the frame.

Historically the main problems related to this sampling technique have been sample disturbance and loss of material as the vibrocore is raised. However, recent developments have concentrated on obtaining high core recoveries and a spring core catcher is commonly fitted to the bottom of the sample tube when sampling sands. Other developments relate to improving and modifying the deployment system, so that the vibrocorer can operate down boreholes, as well as from the seabed.

Vibrocoring has the advantages of being both cheaper and faster than other, more traditional techniques such as wash boring and hammer sampling. 'Continuous' samples may be taken over considerable depths by using the vibrocoring to sample in a cased borehole. Although disturbed, it does provide a reasonably continuous sample of the material to be dredged. It is to be hoped that other techniques which are not traditionally land based in Hong Kong, but which are well suited to the marine environment, will be used more widely in the future.



Vibrocoring during a
nearshore site
investigation for
sands in the Baltic
Sea

Conclusions

Marine investigations to define recoverable sands for fill require careful planning if data relevant to both the Engineer and the Dredging Contractor are to be obtained. This is best achieved by the involvement of the Dredging Contractor at all phases of the investigation and the provision of expert advice to the Engineer.

There are a range of investigation techniques that are commonly used to provide the required data, including geophysical, in situ testing and direct sampling. It is the authors' opinion that in designing an investigation to define marine sand resources, a phased study with inbuilt flexibility is essential. Also reliance should not be placed on one technique alone and a number of different techniques should be employed.

All data needs to be interpreted in its correct geological context and marine investigations represent one area where constant geological input is required. The nature of nearshore deposits is inherently variable and an appreciation of the sedimentological and geomorphological controls on soil distribution allows investigations to be planned and proceed in a cost effective manner.

The emphasis of marine investigations for sands is on developing an overall picture of their distribution, in situ characteristics and obtaining representative samples. This will allow both the Engineer and the Dredging Contractor to assess the technical and economic viability of exploitation, in the context of currently available technology.

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Marine Geophysical Methods

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SUMMARY This paper discusses the technology of marine seismic profiling, and in particular the application of these methods to sand search surveys. The several elements of a complete seismic profiler are described, as well as the operating system and interconnections necessary if the profiler is to operate as an efficient whole. Methods of reduction of observations, interpretation and presentation are also considered, with special reference to the provision and use of interpreted data in digital form. Finally the particular aspects of interpretation of sand search data are discussed. The paper is embellished with Plates and illustrations necessary for a proper appreciation of the inherent complexities of good marine seismic profiling.

The complete seismic profiler

System outline

A high resolution seismic profiler is a device for the production of suitable seismic pulses and for their display after reflection at or below the sea bed. Thus, the end product is an analogue presentation of the sea bed and significant geological horizons beneath it, on which the horizontal axis is distance travelled by the boat, and the vertical axis, time.

The role of the geophysicist

It is the task of the geophysicist, with the assistance of drilling, in-situ and laboratory test results, to rearrange this type of data into a form suitable for the end user.

It is essential that the system be designed so that the geophysicist is freed from the routine operations of navigation, record annotation and data logging, and is thus left to concentrate entirely on securing the highest possible record quality.

Elements of the seismic profiler

The main elements of a seismic profiler are as follows:

- | | |
|-----------------------------|---|
| * Central on-board computer | : Controls all systems for which judgement is not required. Logs all non-seismic profiling data |
| * Positioning system | : Generates X, Y horizontal coordinates |
| Echo sounder | : Provides accurate sea bed levels |
| Seismic power pack | : Provides the power for the sound source |
| * Seismic sound source | : Generates the seismic pulse |
| * Hydrophone | : Receives the reflected seismic signals |

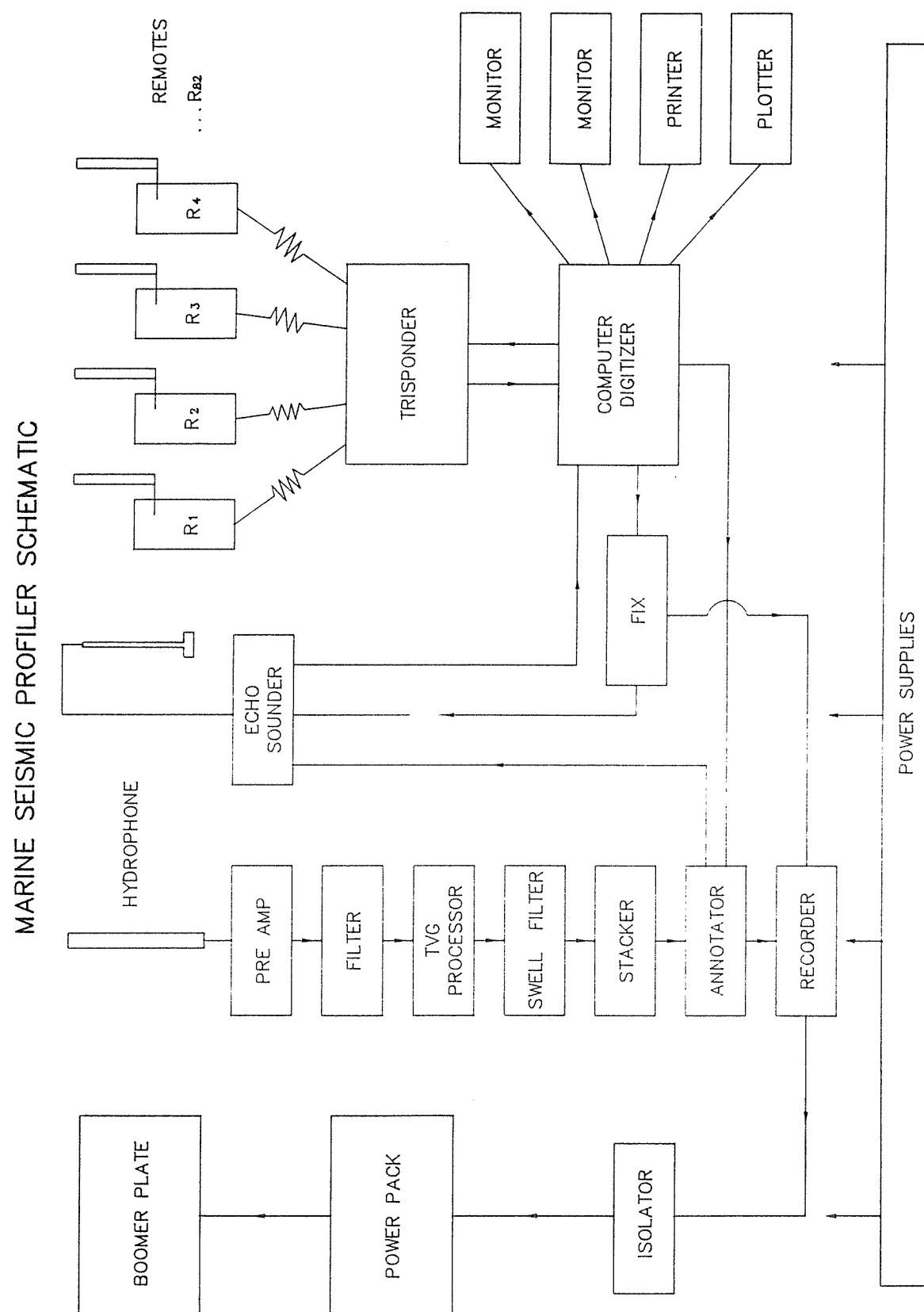


Figure 1. Marine Seismic Profiler - schematic

- * Signal processor : Processes the reflected signals
- * Swell filter : Removes the adverse effects of waves
- * Analogue recorder : Prints the processed seismic signals in analogue form
- Multiple fixing unit : Fixes all instruments
- Record annotator : Inscribes all records with fix number and time
- Assorted power supplies : Separate power supplies for the sound source and electronics

Illustration of the system

Plate 1 illustrates echo sounding, seismic profiling, and positioning equipment in simultaneous use during an investigation for a new power station; it is very obvious that this type of complex deployment cannot be kept in running order without good electronics skill and back-up.

Those items marked with an asterisk are described in more detail later in this paper. Figure 1 shows a block diagram of the complete system.

Seismic sound sources

Applications

Measurements of acoustic wave reflection from sub sea bed surfaces are used in a wide variety of survey applications ranging from the recording of the level and configuration of the sea bed in an engineering geophysical survey, to the determination of the depth of oil bearing strata in an oil exploration survey.

Reflecting surfaces

Acoustic waves will be reflected at interfaces across which the acoustic impedance changes significantly. The acoustic impedance of a material is defined as the product of specific gravity and acoustic compression wave velocity.

Types of seismic pulse

Different acoustic (seismic) sound sources used for bathymetric, engineering geophysical and seismic surveys for oil and gas will emit acoustic pulses with positive and negative-going pressure phases but with different frequency-power spectra.

Power content is related to the area beneath the plotted pulse. Thus, pulses of high frequency and short pulse length will allow the best resolution but with restricted penetration, whilst those with lower frequencies will allow poorer resolution but with greater penetration. It follows that the engineering (and sand search) geophysicist is faced with the difficult task of designing a source with a sufficiently high frequency to provide the necessary resolution, but with a high enough amplitude to secure the necessary penetration of about 100m, necessary for most engineering and sand search applications.

Apparent resolution is commonly always by half-wave rectification at the recording stage, in which only the positive- or negativegoing portion of the pulse is actually displayed.

The 'ideal' pulse would of course comprise only one sinusoid which, after half-wave rectification, would produce a single line reflection, but in practice this is impossible to achieve because all sound sources have a tendency to 'ring'.

The following Table shows the resolution of various profilers, expressed as the thickness of the (half wave length) rectified pulse at various frequencies, and assuming the velocities shown:

Frequency (n) cps	Source	Resolution (m) at Various Velocities (m/s)				Penetration (m)
		v=1500 (water)	v=1600 (Marine Deposits)	v=2000 (Alluvium)	v=3500 (Grade III rock)	
100	Air gun	7.5	8.0	10.0	17.5	5000
500	Sparker	1.5	1.6	2.0	3.5	2000
1000	Boomer	0.75	0.8	1.0	1.75	100
3000	Pinger	0.25	0.27	0.33	0.58	30
10000	Pinger	0.08	0.08	0.1	0.18	10

Penetrations are 'order of magnitude' only; much depends on the actual power output by the source, and on the type of geological succession through which the seismic signals have to pass.

The high resolution boomer

The high resolution boomer, which is probably the most common general-purpose marine seismic profiler, utilises a high voltage pulsed discharge into a copper coil which in turn generates a secondary current in an aluminium plate insulated from it, to produce a sound pulse with a frequency spectrum centred at about 1000cps; the aim is to design for maximum resolution, and this implies that the plate should as far as possible, execute only one sinusoid per pulse. Plate 2 shows a 50 - 300 joule boomer plate designed and constructed in Hong Kong by EGS.

Signal processing

Initial form of the received signal

The reflected seismic signals are received by a multi-element hydrophone incorporating a pre-amplifier with a wide band pass, and amplitude gain of unity and a current gain of about X 10. At this stage, the reflected signals are buried in noise and require much processing before registration on the seismic recorder.

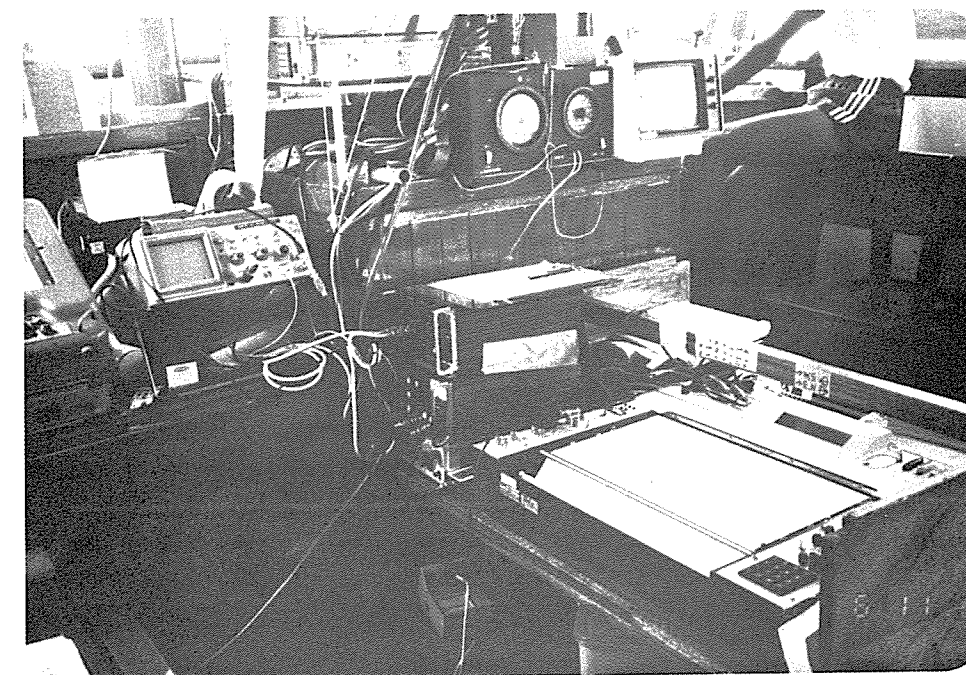


Plate 1. Echo sounding, seismic profiling and positioning equipment in use

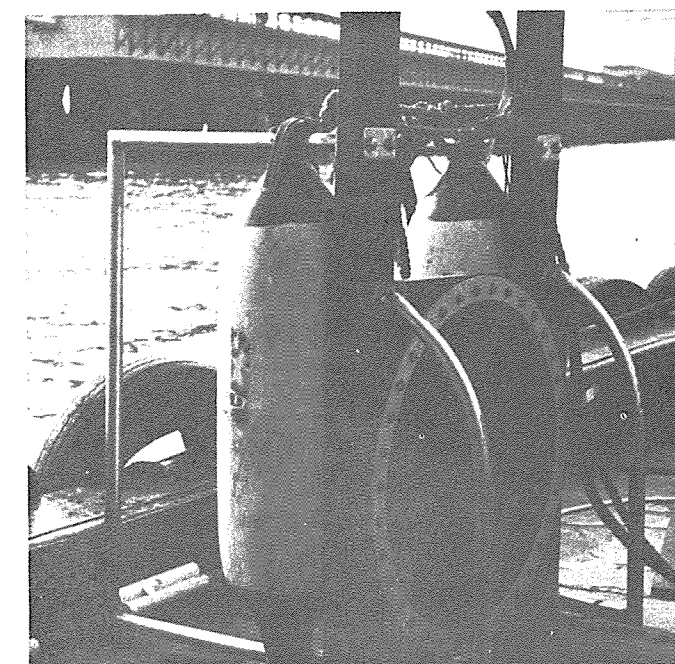


Plate 2. 50 - 300 Joule boomer plate designed and built by EGS Ltd

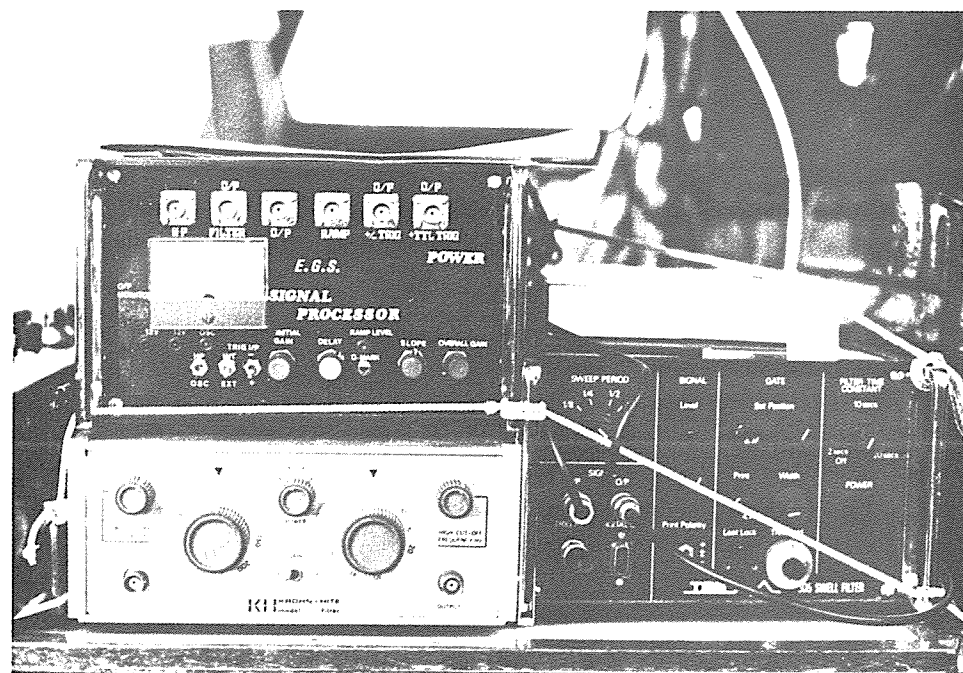


Plate 3. The EGS signal processor

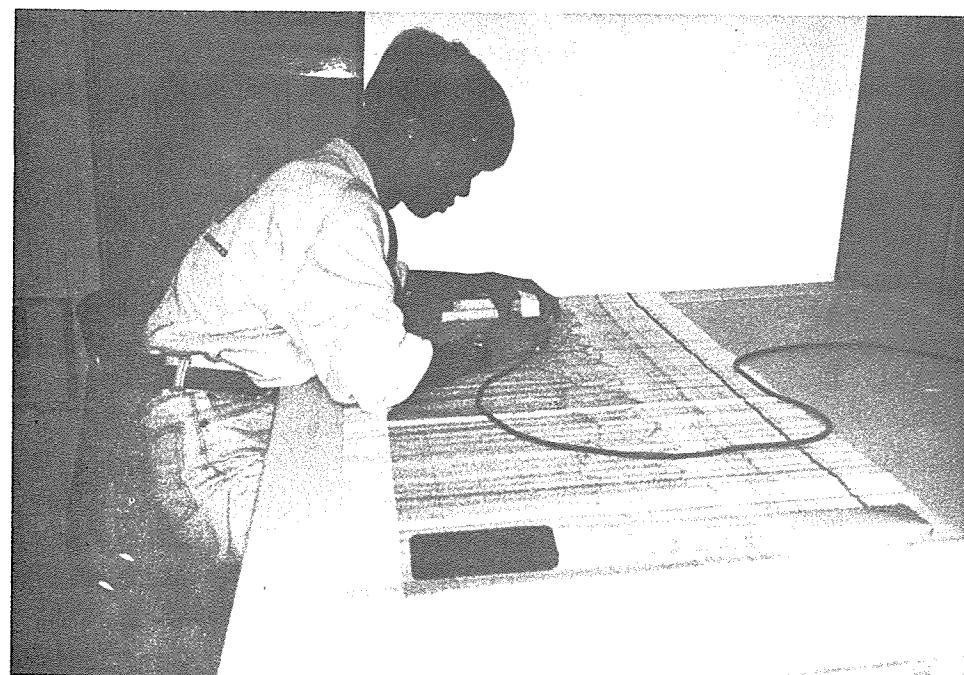


Plate 4. Digitizing of data from seismic traces

Stages of signal processing

The stages of processing are as follows:

Band pass filtering	Removal of unwanted low and high frequency noise emanating from the boat and the surrounding environment
Swell filtering	Removal of the effects of sea waves which are superimposed on the analogue registration and result in a much less clear record
Amplification	At least four different types of amplifier are needed in a good signal processor, especially if good records are to be obtained in less than 5m of water
Stacking	Signal summation for enhancement, and the cancellation of much of the random noise
Recording/registration	The processed signal is recorded on an analogue paper recorder in the form of a stylized geological section along the vessel track (sometimes tape recordings are also made)

Plate 3 illustrates the EGS signal processor. This processor is completely designed and constructed in Hong Kong, with special attention being paid during design to the need to collect seismic profiling data in water depths limited only by the draft of the survey boat.

It can be seen that the processing system is complex, and therefore good records can only be obtained by a geophysicist to whom the different functions of the system are second nature.

It follows that the (all too common) I wonder what this knob does approach to system operation is most unlikely to result in acceptable record quality. The ensuing disasters are sometimes spectacular but more frequently they are covered up.

The consequence is that incompetence in the field is transferred into the office in the form of useless records, where someone else has the unenviable task of trying to extract an interpretation from them.

NAVIGATION SYSTEM SCHEMATIC

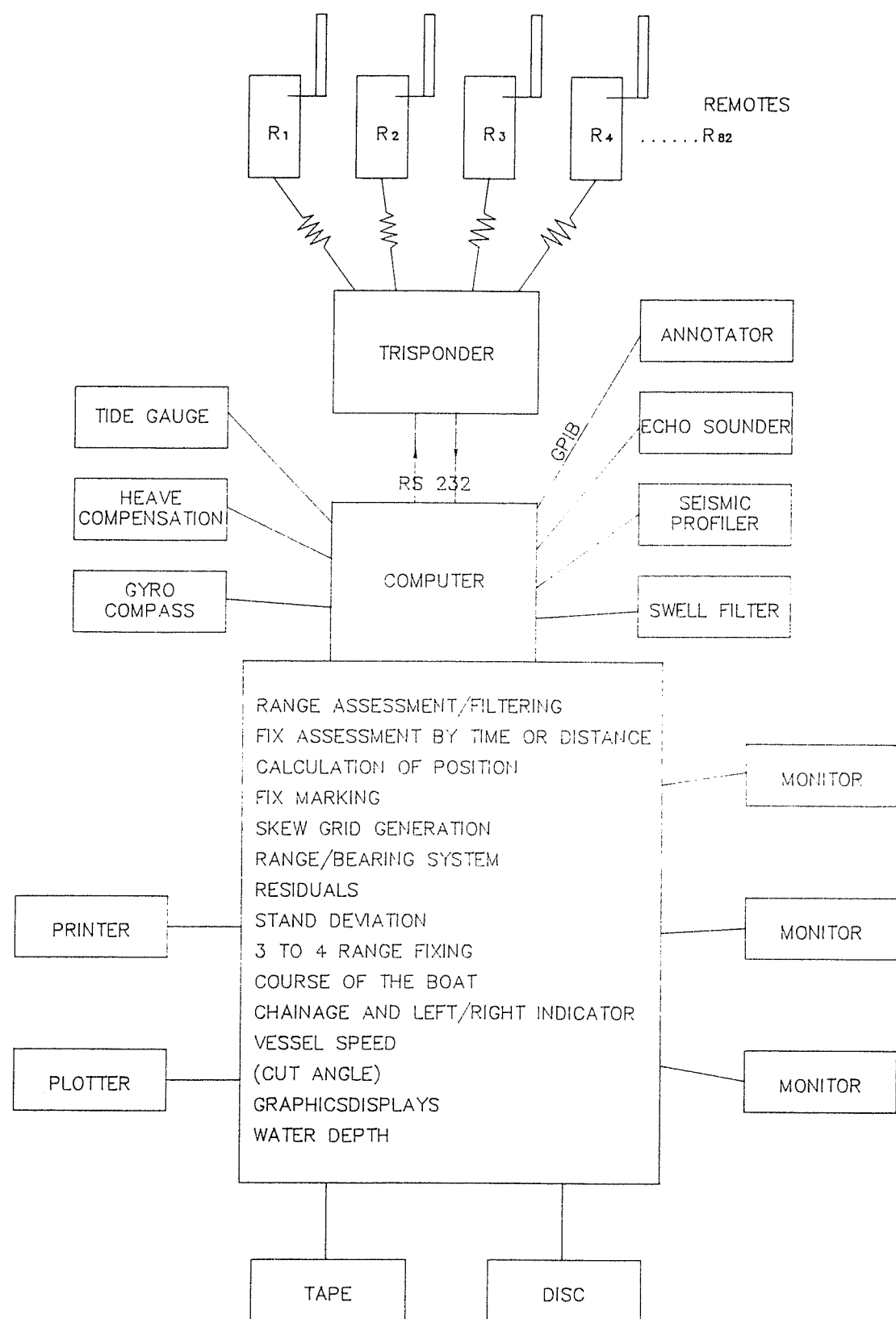


Figure 2. Navigation System - schematic

Position fixing

The central computer

Modern micro-wave electronic positioning systems are able to provide accuracies of $\pm 1\text{m}$ for any range; some systems have a built-in processing capability.

However, there are advantages in the use of a central computer to control not only the positioning system but other functions of the complete profiling system, as follows:

A powerful central computer allows the user to decide not only what parameters need to be displayed for particular applications but also how they should be displayed; this same flexibility applies to printed and logged data

More devices can be connected to a central computer, as indicated in the block diagram of the complete seismic profiling system, and in the block diagram of the navigation system, below

A central computer allows the user to generate different sets of software to suit particular applications, whereas the built-in system allows only for facilities and capabilities provided by the manufacturer and cannot be changed by the user

A central computer system allows the display of positioning information in graphics mode, but this is not the case for built-in systems

A block diagram of a system employing a central computer appears as Figure 2.

Versatility of a central computing system

It should be noted that this type of system allows connections to a wide variety of pieces of equipment, such as a radio tide gauge, a heave compensator, a record annotator, a multiple fixing unit, and a gyro compass, as well as enabling several additional monitors to be installed in different parts of the boat for the convenience of the several members of the survey team.

As stated elsewhere, the main purpose of the positioning system and central computer is to free the geophysicist from all responsibilities except that of obtaining the best possible quality of seismic record.

Calculation of position

Software for the calculation of position includes options for two, three, and four-range fixing. Calculation for two ranges is the fastest, and therefore the most appropriate for very detailed and large scale applications. Three and four-range calculations incorporate a range weighting based on cut angle, and are computed from algorithms which include standard deviations and residuals.

Interpretation and presentation of results

Interpreted data in contoured form

Results are usually presented as a set of contoured levels on discrete surfaces. In Hong Kong, the basic units of the succession which are identified and presented in this way are as follows:

1st surface	Sea bed
2nd surface	Base of Marine Deposits
3rd surface	Top of Rock in Any State of Decomposition
4th surface	Top of Grade III (or less) Decomposed Rock

Ambiguity of sub sea bed surfaces

The sea bed is an unambiguous surface, and as such can be plotted and contoured directly. However, geological surfaces beneath the sea bed are frequently far from unambiguous; not all portions of the above sequence are always present, and it is difficult to be certain of the state of decomposition of the solid geology all over a study area from the seismic evidence, even with the assistance of correlation boreholes. For these and other reasons, errors in the initial interpretation are inevitable.

Cross correlation

Before any sub-sea bed surface can be rendered unambiguous, it has to be correlated at all of the crossing points. Even after this time-consuming process has been completed, special attention has to be paid to the extraordinary complexity of the geometry in cases where horizons are missing, which in the worst case could imply that Grade III rock was at the sea bed. Where this was the case, the contours on all four surfaces would have to agree.

The contouring process

After borehole correlation and final interpretation, the interpreted horizons are digitized (Plate 4) using in-house software, and plotted by machine. Although contouring software applications packages are available, there can be no doubt that contouring itself includes an element of subjective judgement; thus, there is probably no substitute for the practiced geological/geophysical eye when drawing a contour.

Data in digital form

Software packages (such as Moss) are in increasing use by Engineers, and it is now quite common for the data to be requested in digital (tape or disc) form for direct input and subsequent manipulation. The data string usually takes the form $X_i, Y_i, Z_i(1...n)$, where for the i 'th data point,

X_i	is the easting
Y_i	is the northing
$Z_i(1...n)$	are 'n' depths to significant horizons (usually 'n' = 4 for Sea bed Base of Marine Deposits Top of Rock in Any State Top of Grade III Rock)

Seismic profiling for a sand search

It has been emphasized before that there should be no war between boreholes and seismic profilers; indeed, claims that the one can be used to the exclusion of the other do the marine site investigation process, and sand search in particular, a grave injustice. Seismic records cannot on their own provide the end user with the magic quantity of granular fill any more than a set of boreholes on their own can. Seismic records are, however, the only method of providing a display which enables the geologist to understand the sedimentary and hydraulic history of a granular fill prospect, as well as providing the geometry of surfaces bounding different elements of the succession; boreholes complete the picture by furnishing the properties of the materials between these surfaces. A typical sand search could be undertaken in the following five steps:

An initial assessment of areas in which useable deposits of granular deposits are likely to be found. This could take the form of a desk study which takes into account the known geology and hydraulics of the area

An initial seismic survey at a wide line spacing to identify geological units likely to contain useable granular material

A borehole investigation to confirm the general findings of the initial seismic survey, as well as to provide a direct indication of the likely quality of the granular material

A final seismic investigation at a much closer line spacing, to define the seismic horizons more accurately and to enable the calculation of quantities of useable granular material

More boreholes may be required at this final stage to confirm the conclusions

Seismic profiling is a particularly useful tool during the second stage of the investigation outlined above, because of the large area which can be covered in a short period. In the right circumstances up to 50 km of survey line can be observed in a day.

In addition to the preparation of contoured level plans defining the main elements of the geological succession, the preparation of sections is also important. The reason is that sections enable the display of horizons which, although insufficiently persistent to be presented in contour form, may nevertheless be significant for the sand search; for example, the subdivision of Marine Deposits into sandy and silty/clayey portions is frequently treated in this way.

Conclusions

Marine seismic profiling plays an essential part in marine site investigations in general, and in the search for marine sources of granular fill in particular. The method is not a substitute for marine drilling but a complement to it. Success requires close cooperation between geophysicist and geologist

Dredging for Container Terminal 6 A case history

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SUMMARY The dredging at the terminal area was executed according to programme and without noteworthy problems.

Reclamation works were substantially completed in a period of some 6 months (ie in less than 50% of the programmed period), with the bulk of fill importation being completed within 3 months.

Utilization of the marine borrow area was beyond any expectation prior to the execution of the works.

Neither dredging nor dumping of marine mud and sand was found to have an adverse environmental effect though the rates of extraction and dumping were at times considerably higher than had been anticipated during the planning of the works.

The quality of the fill created met all the engineering requirements specified and no remedial or mechanical treatment was needed.

Completion of these works demonstrates the unique ability of modern dredgers to complete a major reclamation project within a period of time impossible by other methods, and with minimum disturbance to the environment.

Introduction

The dredging and reclamation works for Container Terminal 6 at Kwai Chung, commenced in November 1986 and were the first to be executed in Hong Kong using modern large capacity trailer suction hopper dredgers.

Description of the Works

Terminal 6 has been formed by extending the existing facilities at Kwai Chung to the South East by reclaiming land from the sea.

Construction of the new terminal required the removal of some 7 million cubic meters of marine mud from the reclamation area followed by the placing of 8.6 million cubic metres of marine sand to construct the formation for the new terminal.

Formation works were programmed to be completed within two years of the commencement of work.

Design philosophy

The terminal was required to be brought into operation as rapidly as possible. Design studies showed that the most cost effective method of

providing a stable formation within the required time period was to excavate the marine mud at the terminal site and form the reclamation on the underlying alluvium. This required excavation from existing sea bed to between -20 and -30m.

Two marine borrow areas were located, to the North and South of the Eastern end of Lantau Island, some 5 and 12 km from the reclamation site respectively (Figure 1).

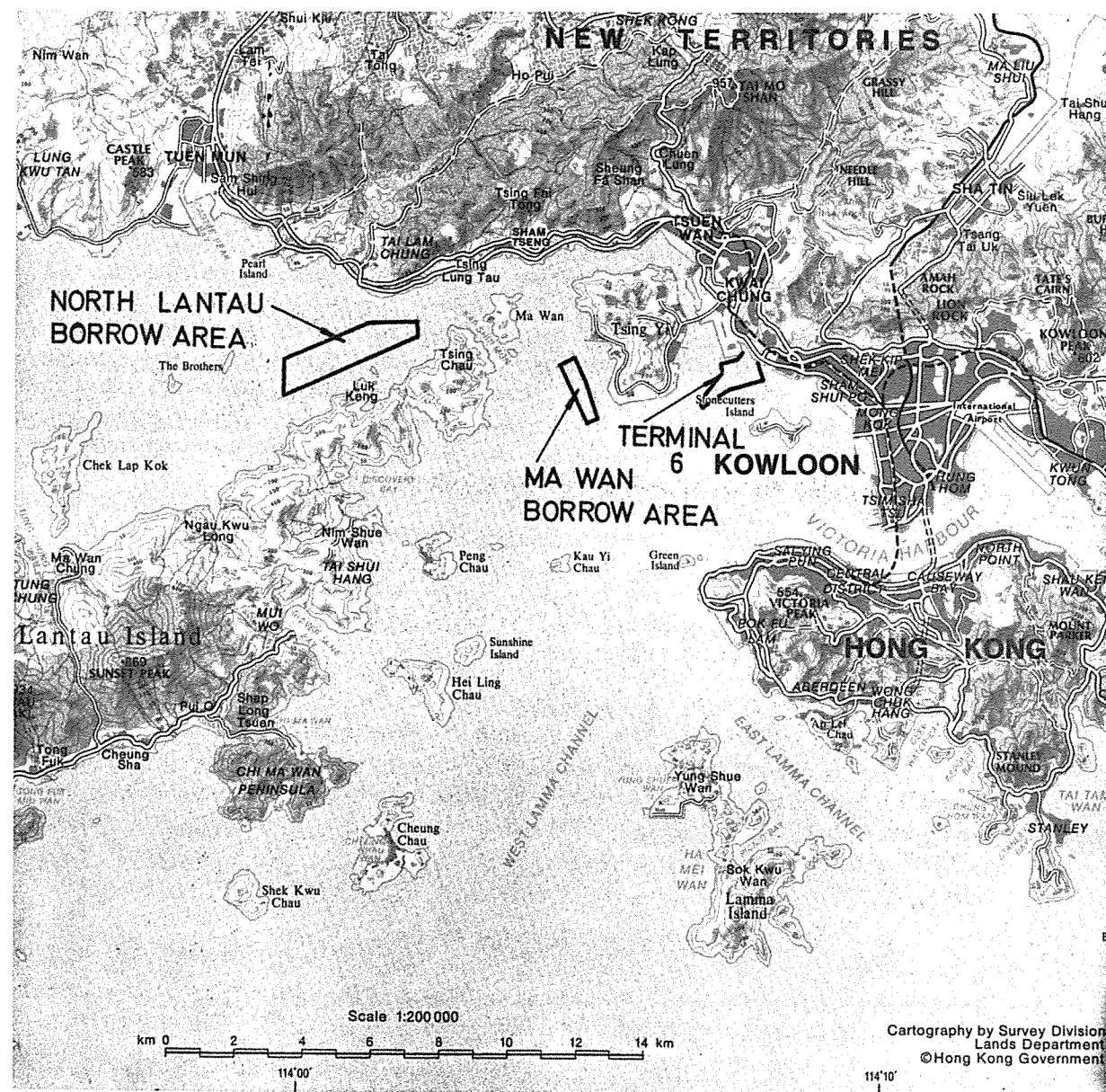


Figure 1 Location of Container Terminal 6 and the marine borrow areas

Site Investigation showed that these sites contained substantial volumes of both marine and alluvial sand intermingled with silt and clay.

Considerable attention was paid to the possible adverse environmental effects of both excavation and disposal of marine mud, and the borrowing and deposition of marine fill. Extensive water quality monitoring was therefore required during the currency of dredging and reclamation work.

Monitoring of fill quality and performance was to be by means of post deposition sampling and testing and by the installation of settlement plates at the base, middle and top of the reclamation.

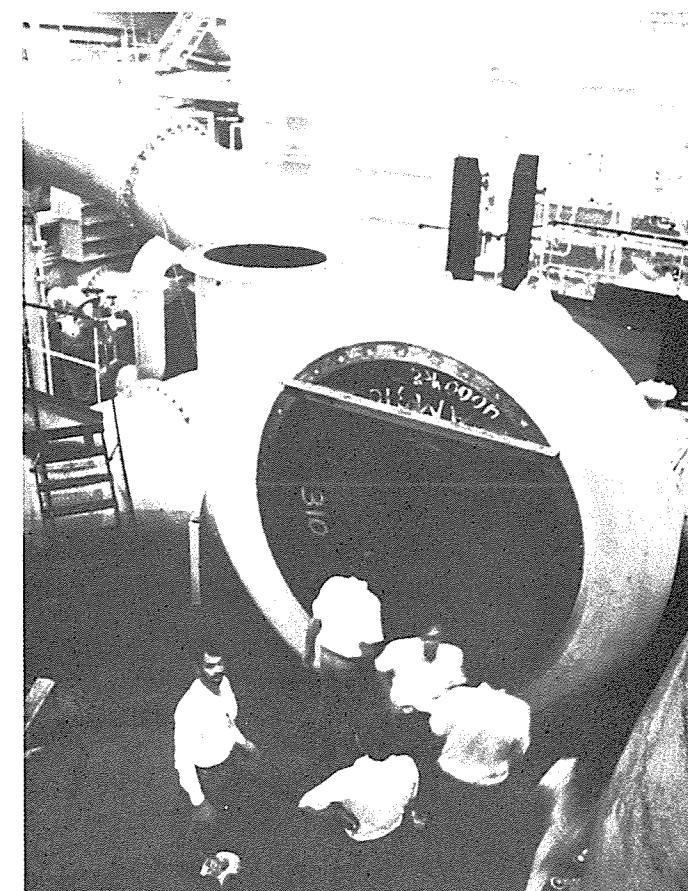


Plate 1 Pump room of the "HAM 310" showing a disconnected centrifugal pump

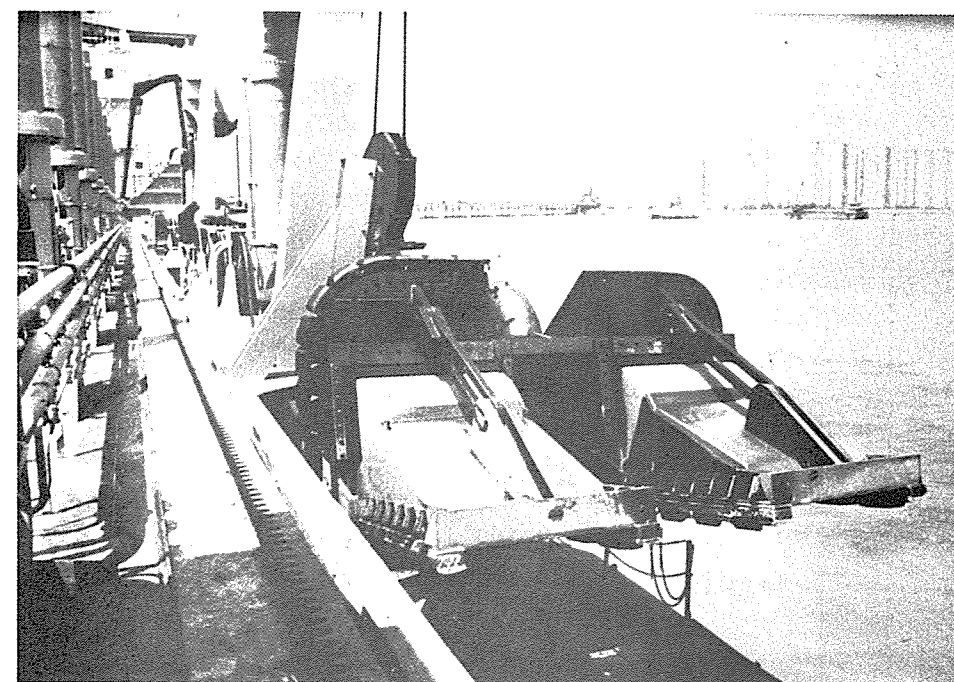


Plate 2 'California Draghead', used for loading marine sand, on the "HAM 310"

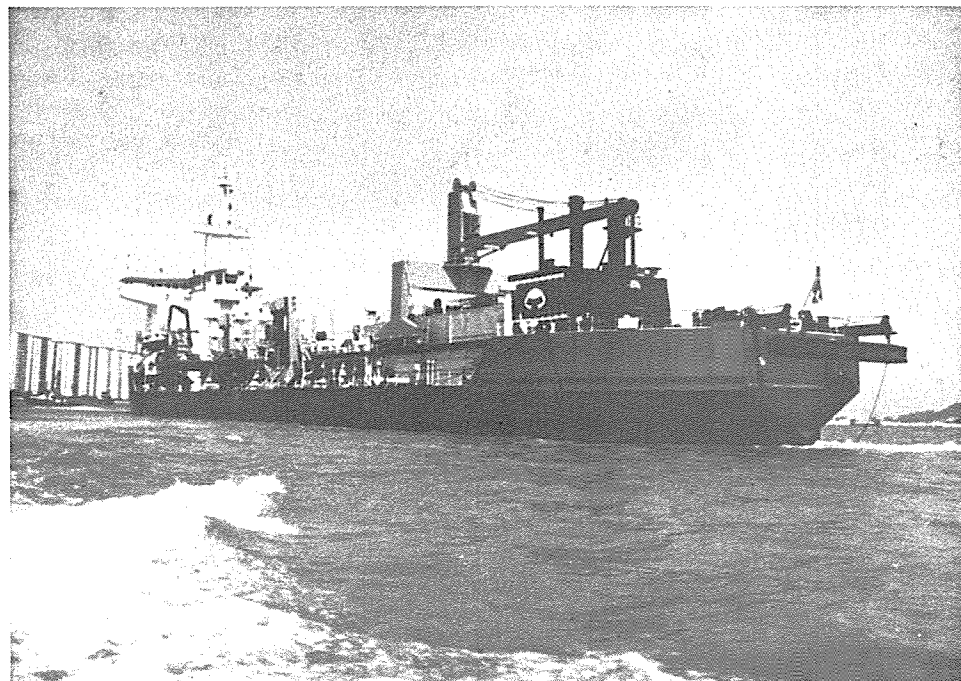


Plate 3 "HAM 310" at the Container Terminal 6 site during the operations to remove the marine mud. Note the 'submarine plough' beam mounted at the stern, to assist the loading of marine mud.

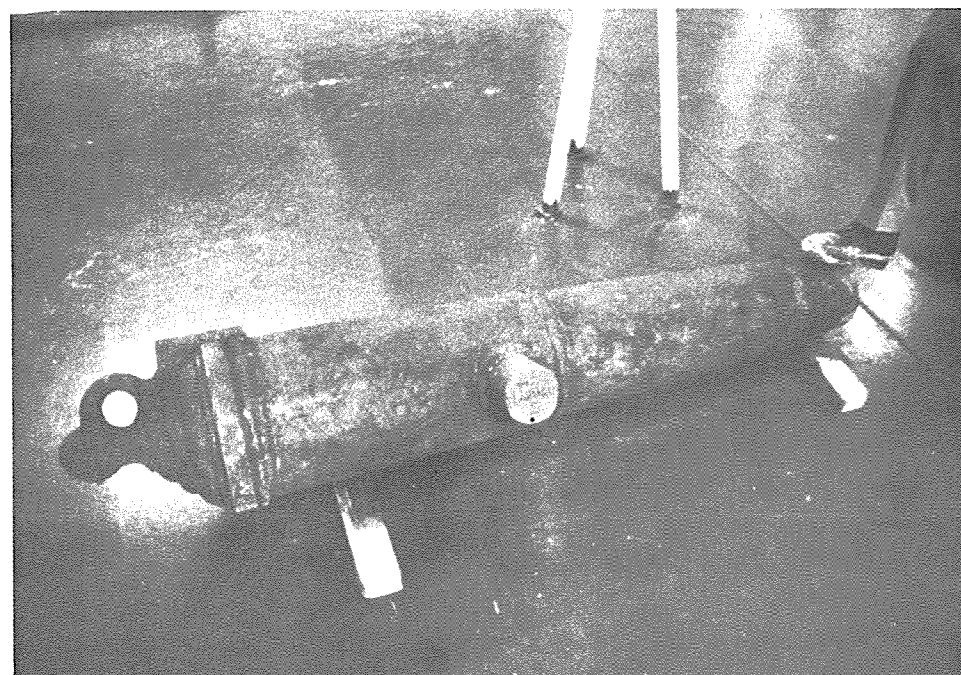


Plate 4 Early 19th century muzzle loading cannon removed from one of the dragheads of the "HAM 310" during marine mud removal operations at the Terminal site.

Methodology

Consideration of the nature and location of the terminal site, designated borrow areas and available marine dumps led to the expectation that the works would be executed using medium/large trailer suction hopper dredgers. These dredgers, working 24 hours per day, 7 days per week (save for perhaps half a day per month for bunkering), load sea bed material by means of powerful suction pumps located within the hull, via dragheads attached to suction pipes, into an integral hopper. During loading the dredgers maintain slow ahead speed (Plates 1 and 2).

After loading, the dredgers sail at high speed to the dump or reclamation area and unload the hopper via bottom doors or by pumping over the bow. Such dredgers can operate in swells of up to 3m and in crowded and confined waters since they are equipped with a swell compensation system, twin screws and single or double pairs of bow thrusters.

In order to minimise the amount of alluvium inadvertently loaded during the marine mud removal, re-definition of the top of alluvium profile was required when the level of dredging approached the predicted top of alluvium profile. Vibro-coring was specified and it was initially anticipated that rigs would be free standing on the sea bed, although in the event, pontoon mounted equipment was used. In other respects the dredging at the terminal site was a standard trailer suction hopper dredger operation.

Reclamation was required to be sampled and tested in 3m lifts, no overfilling being permitted prior to the availability of the results of grading tests made on the samples. Vibro-coring was again specified for the fill sampling.

Rock retaining bunds were detailed, to mirror the fill lifts in the lower parts of the reclamation, and extensive areas of the site were required to be surcharged with embankments some 3m high.

Water quality monitoring required the use of both direct reading meters and sampling followed by laboratory testing. Monitoring was carried out both in the vicinity of dredging and reclamation operations and at other locations distant from the work areas. Monitoring during the design phase of the works was carried out to establish base line values for water quality parameters. Principle parameters considered were suspended solid and dissolved oxygen content.

No overflowing during marine mud dredging was permitted and overflowing during the loading of marine fill was restricted.

The specification for the reclamation limited fine material to 20% generally and 30% absolutely. These percentages are somewhat higher than those generally used when free draining fill is required but typical of Hong Kong fill specifications.

Measurement was generally to paylines, some being vertical, so that a significant volume (about 15% of the total) of non-payable dredging was to be carried out.

Dredging of the Terminal area

Following the completion of the pre-dredging survey in the latter half of October 1986, dredging of marine mud at the terminal area commenced using the large trailer suction hopper dredger 'HAM 310' (Plate 3). This dredger was joined by the medium size trailer suction hopper dredger 'HAM 308' at the end of December 1986.

The pre-dredging survey had revealed sea bed levels in the dredging area to be higher than those indicated by survey data available at the time

of tender. These higher sea bed levels resulted in loading operations being disrupted to some extent, during the removal of the upper layers of marine mud.

Loading operations were also adversely affected by quantities of rock, bombs and marine equipment (ranging in age from 0 - 150 years old) which had to be removed from the dragheads, suction pipes and pumps (Plate 4).

Analysis of pre-contract seismic surveys had suggested the presence of biogenic gas in the marine mud to be dredged. Dredging proved this supposition to be correct. Use of de-gassing equipment on the dredgers might have improved hopper specific gravities, but it was considered that the short duration of the marine mud dredging programme did not justify installation of the equipment.

Vibrocore sampling, carried out in the later stage of the mud dredging using pontoon mounted vibrocore equipment showed that the top of alluvium profile was highly irregular, the smooth depositional profile having become deeply indented as a result of weathering prior to the deposition of the overlaying marine mud. Trailer suction dredgers are not optimised to dredge such profiles and cleaning of the mud/alluvium interface required about one month of the five-month dredging programme. Dredging of the terminal area was substantially completed by the 1st April 1987, but cleaning operations continued until the 3rd week of April.

Reclamation for the Terminal

Reclamation for the terminal area commenced on the 1st April 1987 (whilst as noted above, cleaning of the top of alluvium profile continued). Reclamation was initially by loading marine sand at the Ma Wan borrow area and deposition by bottom dumping at precise, pre-programmed locations within the terminal area (so that the required 3m lifts could be achieved).

Positioning was by means a precision electronic survey system with an accuracy of better than 1m, and in the case of the 'HAM 310', the vessels dynamic positioning system (Plate 5).

Water quality monitoring showed that considerable washing of sand during extended loading could be permitted so that, in practice, any material that could be economically loaded was deposited as fill.

Reclamation proceeded rapidly during the month of May 1987 using between two and three trailer suction hopper dredgers (the 'HAM 310' and '308' being joined for part of the month by the 'P.C.S. Van Hatten'), with in excess of 1.1 million cubic meters being placed during one week. Progress at such a rate required the use of three double ended sampling barges and a site laboratory working 24 hours per day, 7 days per week to meet the specified requirements for testing of the fill.

The rate of progress of reclamation slowed after the level of fill had reached the limit of bottom dumping (about -8m), by which time some 5 million cubic meters of fill had been placed. Reclamation was thereafter achieved by pumping from the hopper, either through a bow nozzle, or via a floating pipe line (increasing the length of the dredgers cycle by about 30% and therefore reducing the rate of filling) (Plate 6).

Progress of primary reclamation had considerably exceeded that envisaged by the programme. This was due, both to the use of additional dredging plant and the complete utilization of the Ma Wan borrow area (Pre-contract estimates assumed that only between 2 and 4 million cubic meters of the some 8 million cubic meters that were expected to be dredged from the Ma Wan borrow area could be used as fill).

The Contractor elected to continue reclamation at a relatively high rate during the months of June and July, stockpiling fill within the

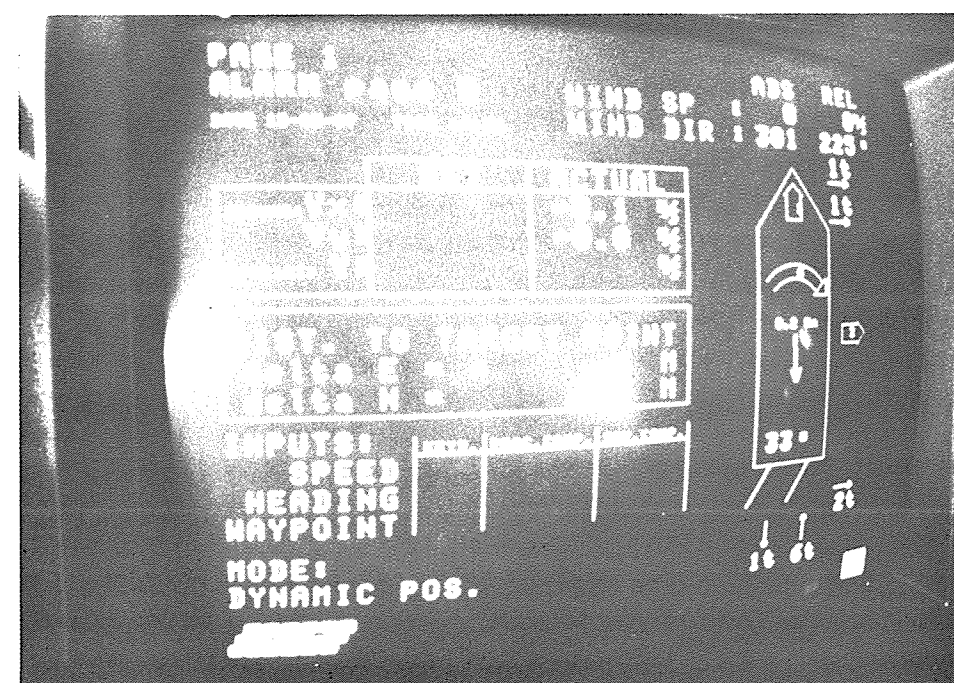


Plate 5 Display monitor for the dynamic positioning system on board the 'HAM 310'. The system is being used to hold the dredger in position while pumping marine sand onto the reclamation via a floating pipeline.

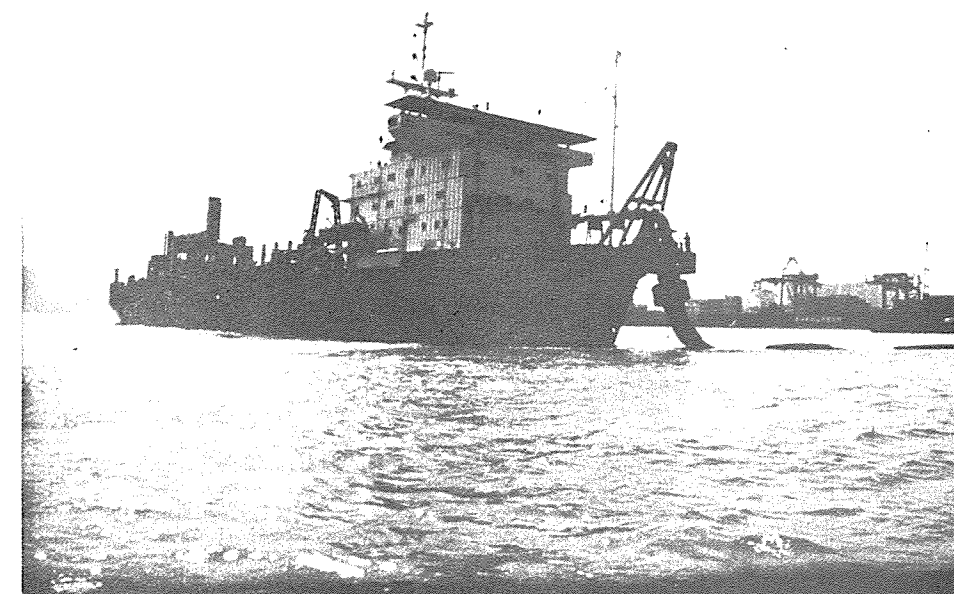


Plate 6 "HAM 310" pumping marine sand onto the reclamation area via a floating pipeline.

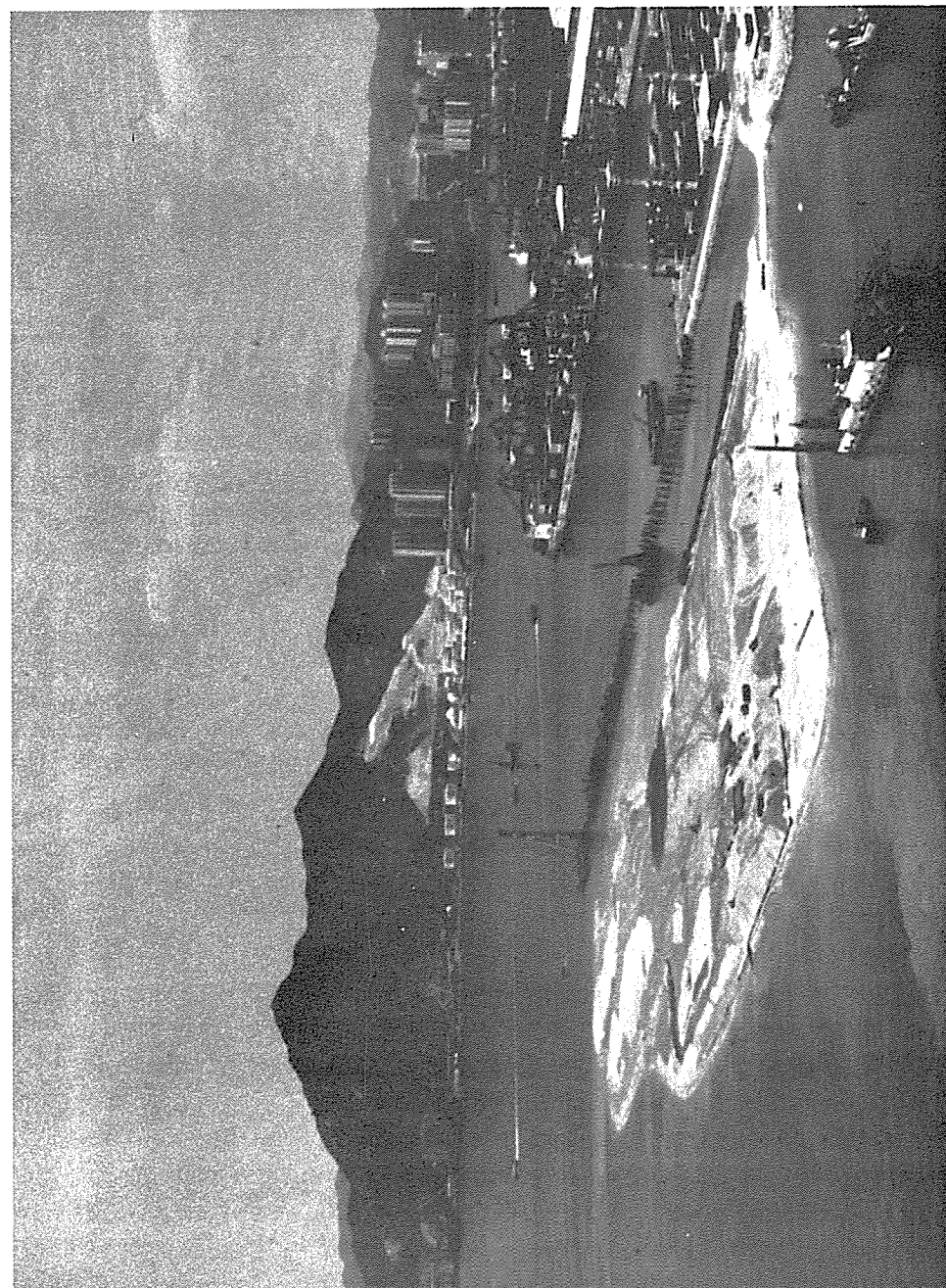


Plate 7 General view of the reclamation site showing the cutter-suction dredger "Yu Long", and the bucket dredger "HAM 112".

terminal site where it could not be placed in its final location by the trailer dredgers. By mid-July some 8 million cubic meters of material had been brought to the terminal area so that the 'HAM 310' was demobilised and operations by the 'HAM 308' suspended by the end of that month.

Re-handling of material stockpiled in the terminal area and trimming of reclamation side slopes was undertaken by a medium-sized cutter suction dredger which began operations during July 1987, pumping fill material to parts of the reclamation not accessible to the trailer dredgers, and forming the 3m high surcharge embankments where they were required. A bucket dredger and lighter-mounted grabs also assisted in slope trimming work. An aerial view of the reclamation is shown in Plate 7.

Importation of fill from both the Ma Wan and North Lantau borrow areas to the reclamation by the 'HAM 308', was resumed in October 1987 and continued at a low rate until the 1st December 1987.

Of the some 7500 soil samples tested, less than 0.5% were in technical breach of specification and no remedial work to the fill was required. Use of dredgers to place fill by hydraulic methods for parts of the reclamation above sea level obviated the need for mechanical compaction. The amount of reclamation settlement experience, fell within the predicted range.

Completion of these works demonstrates the unique ability of modern dredgers to complete a major reclamation project within a period of time impossible by other methods, and with minimum disturbance to the environment.

Marine Sand
Foundation For The Eastern Harbour Crossing

A.I. Thomson

EHC Project Management Company Limited

SUMMARY: The Eastern Harbour Crossing, presently being constructed, is the first of Hong Kong's three immersed tube tunnels to be founded on a bed of sand placed in-situ after positioning the units on temporary supports in the dredged trench. Although the concept of a sand foundation has been used many times before, the contractor has developed a new technique for placing the sand for this project. A series of large scale tank tests were undertaken in Japan and in Hong Kong to prove the system and to determine the pumping characteristics of the sand. A market research was carried out in Hong Kong and in the Peoples Republic of China to find the most economic source of marine sand with the required qualities. At the time of writing the first tunnel unit has been successfully immersed in its final position in the waters of Hong Kong harbour and the sandplacing operation is about to commence.

Introduction

The Eastern Harbour Crossing is, by virtue of its length and width, probably the largest immersed tube tunnel in the world. The phrase immersed tube tunnel describes the construction technique whereby concrete units are fabricated on shore, towed out to the waterway, sunk into position in a dredged trench and joined underwater to form a continuous tunnel below the waterway.

The Eastern Harbour Crossing is a combined road and rail connection between Hong Kong Island at Quarry Bay and Kowloon at Cha Kwo Ling. The tunnel consists of 15 precast reinforced concrete units being manufactured in a dry dock located in the basin of a redundant quarry in Cha Kwo Ling. Each unit contains five separate conduits - two accommodating the railway, two for the road and a fifth housing environmental control systems.

A characteristic feature of an immersed tube tunnel is that the load to be carried by the foundation in general will be very low. In the case of the Eastern Harbour Crossing the normal bearing capacity to support the immersed tube is approximately 20 kN/m²; in the extreme case where there is 2m of siltation and a sunken ship resting on a tunnel unit this increases to about 80 kN/m². This may be considered as very low taking into consideration that the width of the tunnel is greater than 35m. Besides at least 12m depth of material was dredged from above the formation level which effectively produced surcharge loadings of greater than 100 kN/m². Therefore the placing of an immersed tube unit will normally lead to a reduced stress level in the subsoil. The dredged formation level occurs in mixed alluvium and all material exposed to date has been suitable subsoil to support the immersed tube tunnel units.

To ensure a uniform bearing for the units on to the undulating dredged trench it is necessary to introduce a placed level bed of sand or gravel.

Development of foundation method for immersed tunnels

The earliest immersed tube tunnels were founded by placing the unit on a prepared screeded bed of gravel. Indeed this method was used for Hong Kong's other two immersed tube tunnels; the Cross Harbour Tunnel and MTRC Rail Tunnel. The world's first screed-and-lay barge was developed by the contractor to place the screeded mattress and lay the units for the Cross Harbour Tunnel. A layer of crushed rock 600mm thick was placed and screeded to ± 25 mm using the specially developed rig shown in Figure 1. The screed-and-lay barge could also be used to place the units themselves which were approximately 22m wide. A similar screed-and-lay barge was built to place the 13.1m wide units for the MTRC rail immersed tube tunnel.

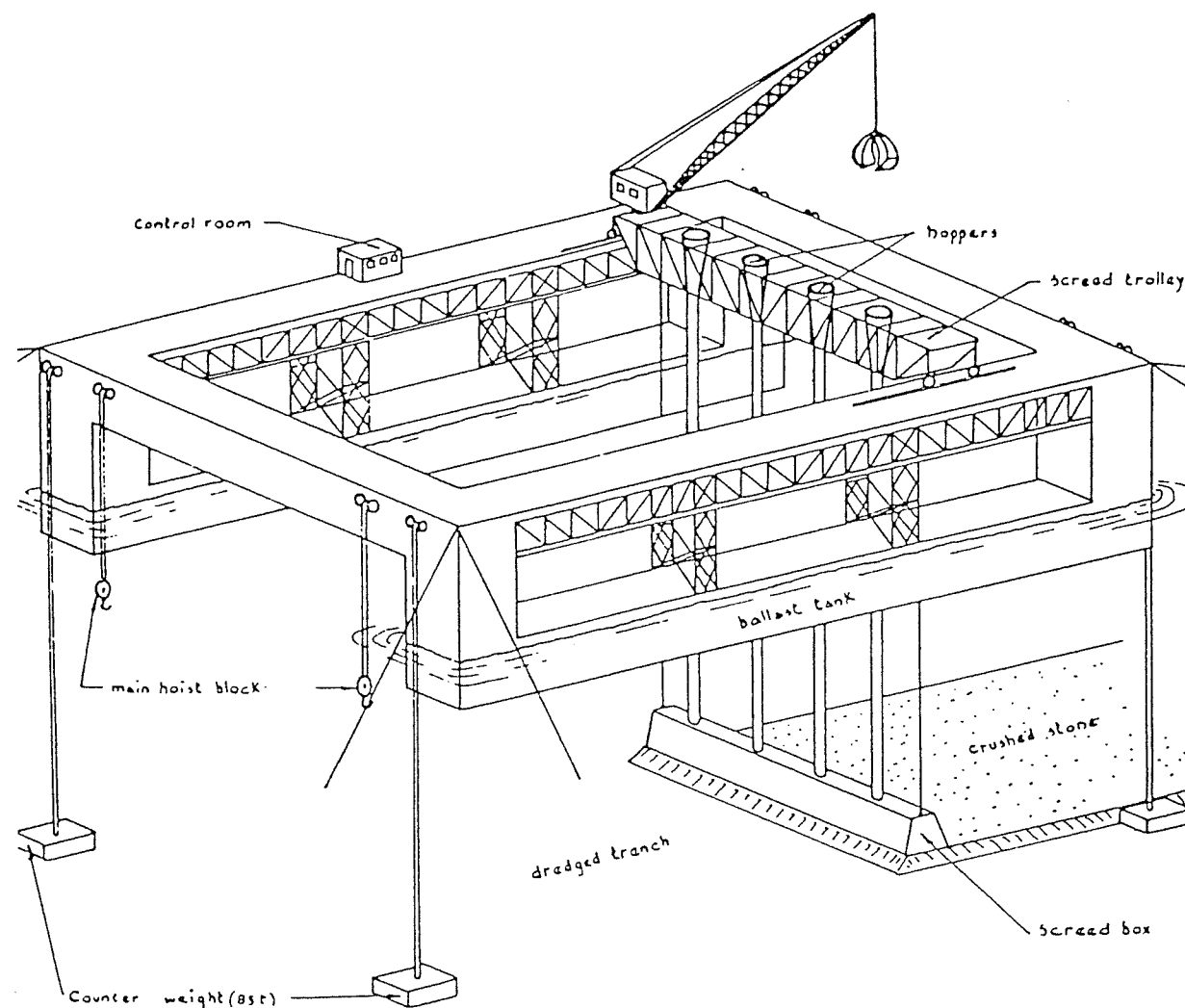


Figure 1. Screenshot-and-lay barge

About 50 years ago a new concept in foundations for immersed tube tunnels was introduced. Sandjetting, sandflow and sandplacing are three different words for the same basic thing; and that is to place a prefabricated immersed tunnel unit on temporary supports in its correct position and thereafter to fill the space between the underside of the tunnel element and the excavated trench bottom with sand. To decide to do this for the first time was a very brave decision which required much self-confidence and a firm conviction that the basic laws of nature had been understood. A contractor introduced the concept for the first time as an alternative design to the specified screeded bed. Only a contractor could introduce such a method, since only a contractor with the required knowledge and self-confidence and resources could back up the proposal with a guarantee of a satisfactory tunnel as the final result.

However, when first it has been done successfully and has proved to be a practical and competitive construction method it does not require so much courage to follow the example set or even to propose improvements. There are today several ways of pumping sand underneath an immersed tunnel. They differ in detail, but they all have one basic feature in common: the sand particles move along with the pumping water when the velocity is above a critical velocity and they will settle when the velocity drops below this figure. By and large the methods of placing the sand fall into two broad categories so called sandjetting and sandflow.

Benelux Tunnel, sand jetting gantry
a. gantry movable along tunnel axis
b. pipe system for sand supply
c. temporary foundation
d. jetted sand

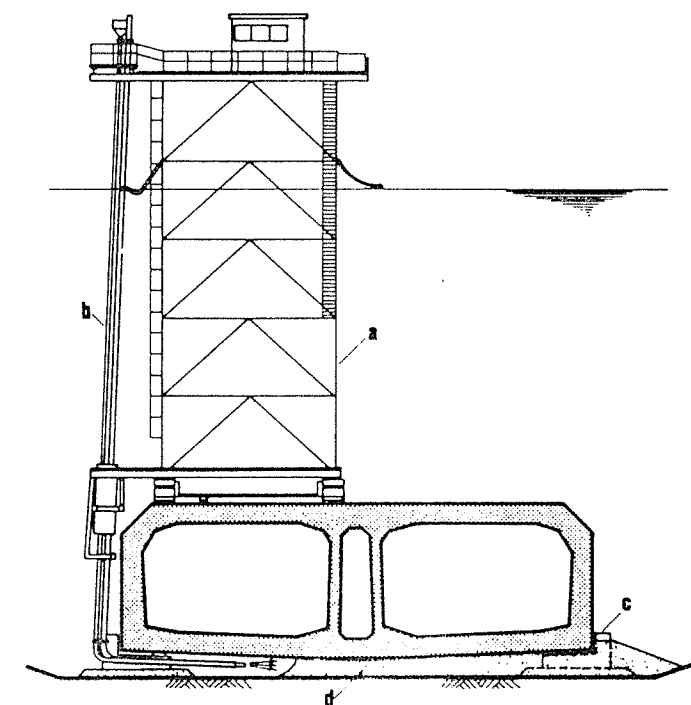


Figure 2. Sandjetting gantry

The sandjetting method was developed by the Danish contractor Christiani and Nielson. With this method a mixture of sand and water is jetted through pipes inserted into the clearance between the bottom of the

tunnel and the dredged trench. Usually with this method a gantry rides longitudinally along the roof of the tunnel and transverse movement of the nozzle is achieved by winching along the top of the gantry or by swinging the nozzle in a series of concentric arcs. Two delivery systems are required with one nozzle being inserted under each side of the tunnel. The reach of the jetted sand can also be varied by adjusting the exit velocity of the sand. A typical gantry arrangement is shown in Figure 2.

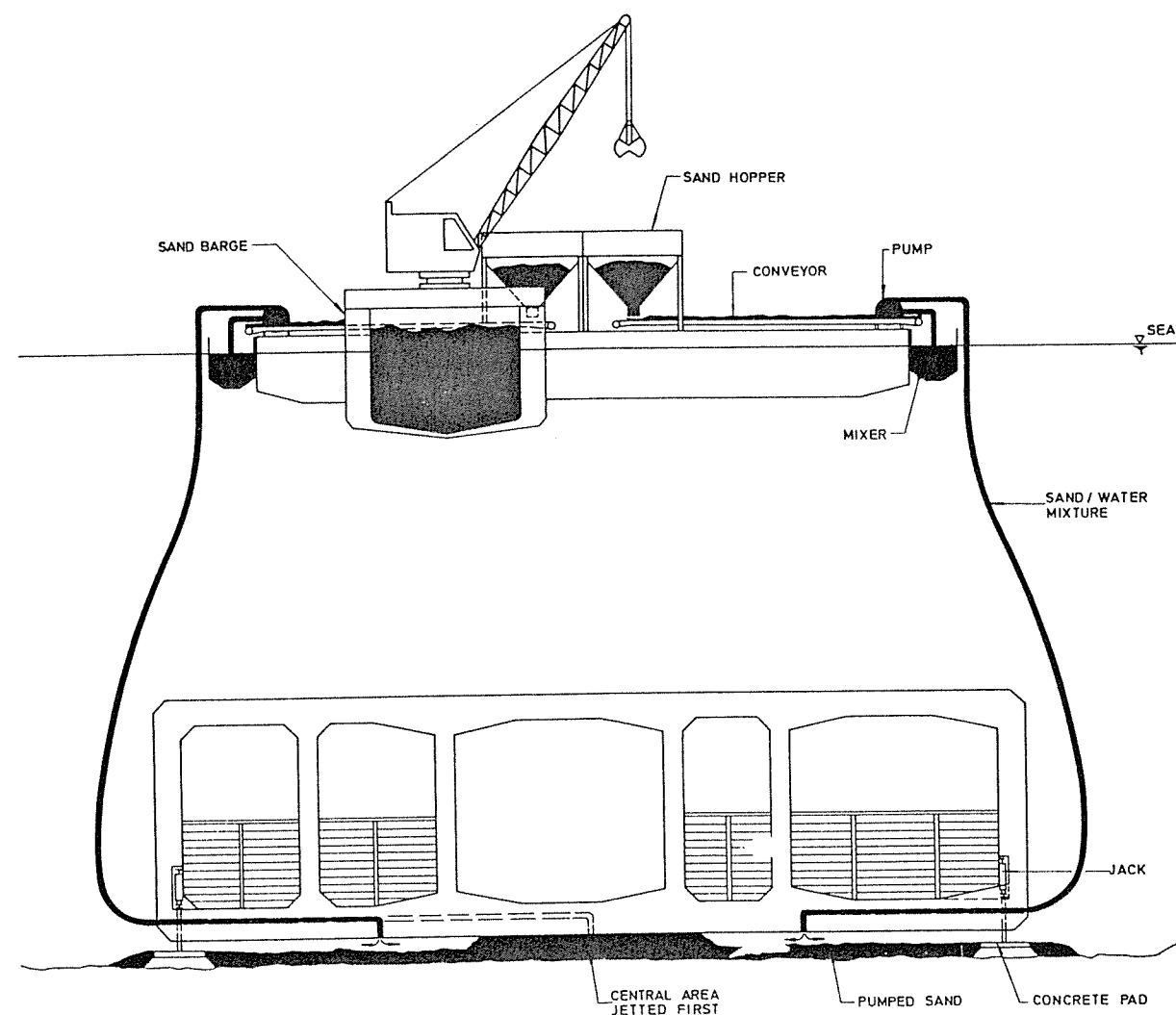


Figure 3. Sandflow method

The sandflow method was developed by the Dutch contractor Ballast Nedam Group during construction of the Westerschelde crossing in the nineteen-seventies. This river carried intensive shipping traffic to Antwerp and the current velocities were up to 2m/sec. It was obvious that the idea of a sandjetting gantry riding across the river on the roof of the tunnel would present many difficulties. The sandflow method utilises pipes cast into the base slab of the units to deliver sand

vertically downwards through the soffit. In the first phase of the process after leaving the discharge opening, the sand will be transported in all directions to form a circular pancake in the clearance under the tunnel. The sand continues to build up a flat cone with a crater in the middle until eventually the top of the cone touches the underside of the tunnel. At this moment the second phase of deposition builds up when a "river" will break through the rim of the cone and start to flow transporting the sand to the outer slopes. There the sand will settle and widen the cone until a limit is reached which depends on the pumping parameters. The radius of deposit can be greater than 12m in some cases.

By casting pipes into the base slab in a grid with suitable spacings centre to centre, the whole of the underside of the unit can be filled up by a series of overlapping flat-top cones. A schematic arrangement is shown in Figure 3.

Type of foundation chosen for Eastern Harbour Crossing

Both the screeded bed and pumped sand foundations have a well proven track record of providing perfectly satisfactory foundation for immersed tube tunnels worldwide. The choice of the type of foundation depends on the practical problems of placing the foundation material and not generally on any theoretical engineering restraints. The practical cost and programme considerations justifying the choice of construction method can best be explained by the contractor. In any case, it is the contractor who has to do the work, so it must be his choice how it is to be done, as long as the quality does not suffer.

Kumagai Gumi Company Limited of Japan is the design and construct contractor for the Eastern Harbour Crossing. The choice of foundation adopted is theirs. Kumagai Gumi have been involved in recent years with several immersed tube tunnel projects including Tokyo Bay, MTRC rail tunnel in Hong Kong, Kaohsiung in Taiwan and Sydney Harbour in Australia. They possibly have more experience than any other contractor of construction of immersed tube tunnels in the last 20 years. It was natural that Kumagai Gumi should want to develop a better technique that could be associated with their name just as the sandflow and sandjetting methods are associated with the contractors that first developed them.

A screeded bed of aggregate was eliminated very early on. At 35.45m width, the Eastern Harbour Crossing units are considered to be too wide. A catamaran screed-and-lay barge would need to be nearly 50m wide overall and would not have been cost effective to build. Besides it is quite obvious from a purely practical point of view that it is quicker and more convenient to place the tunnel element first on adjustable supports, which can be done very accurately without interference from waves and tidal variations, than it is to prepare a foundation bed for the tunnel unit to come to rest on. So, a pumped sand foundation became the obvious choice.

Kumagai Gumi considered that the sandflow method had the following disadvantages that swayed them against choosing this method.

- (a) It required pipes to penetrate the protective waterproofing skin of steel plates.

- (b) It is impossible to completely fill with sand the crater immediately below the discharge pipe and bentonite cement grouting may have been necessary to guarantee the adequacy of the foundation.
- (c) Disconnection of delivery pipes and reconnection to the next discharge point would have had to be carried out underwater requiring time consuming diving operations.

The contractor considered that the previously used sandjetting methods also had the following disadvantages which weighed against them.

- (a) The biggest disadvantage is the need for a gantry riding on top of the tunnel. Hong Kong harbour is very busy in terms of marine traffic and there would have been a danger of collision with a vessel. Also the gantry would have been vulnerable to damage by typhoon conditions.
- (b) There was some doubt as to the accuracy of verification methods used to prove that the sand had been adequately placed.

Kumagai Gumi set out to develop a new method which combined the best characteristics of both the sandflow and sandjetting methods as follows:-

- (i) Theoretically the system should be capable of placing sand so that 100% of the bottom of the unit is supported.
- (ii) No travelling gantry above the unit.
- (iii) A simple and effective means of verifying that the sand had been adequately placed.

The contractor conceived the idea of placing sand in straight transverse strips and they have chosen to call it the sandplacing method. The sand is mixed with water on a flat top barge floating on the surface and the mixture is pumped through two flexible hoses to an underwater nozzle system which is shown in Figure 4.

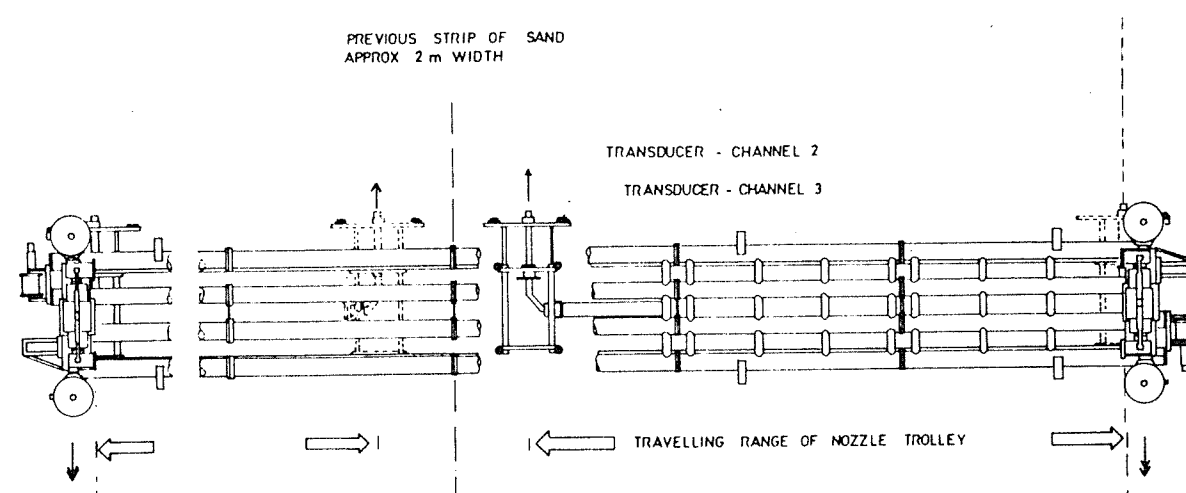


Figure 4. Plan of sandplacing equipment

The system is symmetrical about the centre line of the unit. A discharge nozzle is held 300mm below the soffit of the tunnel unit and is connected to the delivery pipe. When the mixture is pumped it is discharged horizontally and parallel to the longitudinal centre line of the tunnel unit. After a certain length of pumping time the nozzle is winched horizontally and transversely 1m towards the outside of the unit, pumping is continuous during the whole operation. This incremental movement is repeated until a straight strip of sand has been placed transversely under the unit. By a series of clamping and unclamping of hydraulic rams the whole nozzle system is moved 2m longitudinally away from the previously placed strip. The operation is repeated until another 2m strip of sand has been placed and in this way a whole series of 2m strips is placed until the whole of a tunnel unit is supported. The system also includes 4 horizontal and 4 vertical air tanks to provide positive buoyancy which produces the reaction forces required.

Large scale laboratory tests

Once the idea had been developed in principle it was necessary to demonstrate that the following assumptions made by the designer of the immersed tube structure could be achieved in practice.

- (a) A regular flow and deposition pattern for the sand could be created.

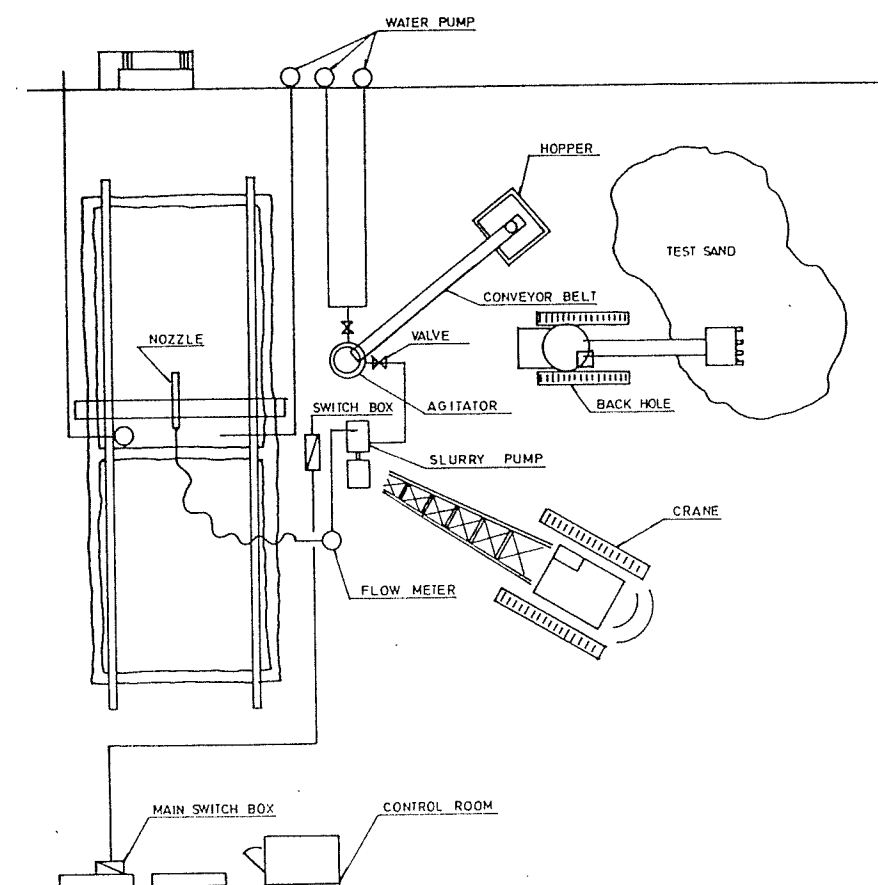


Figure 5. Plan of large scale test tank

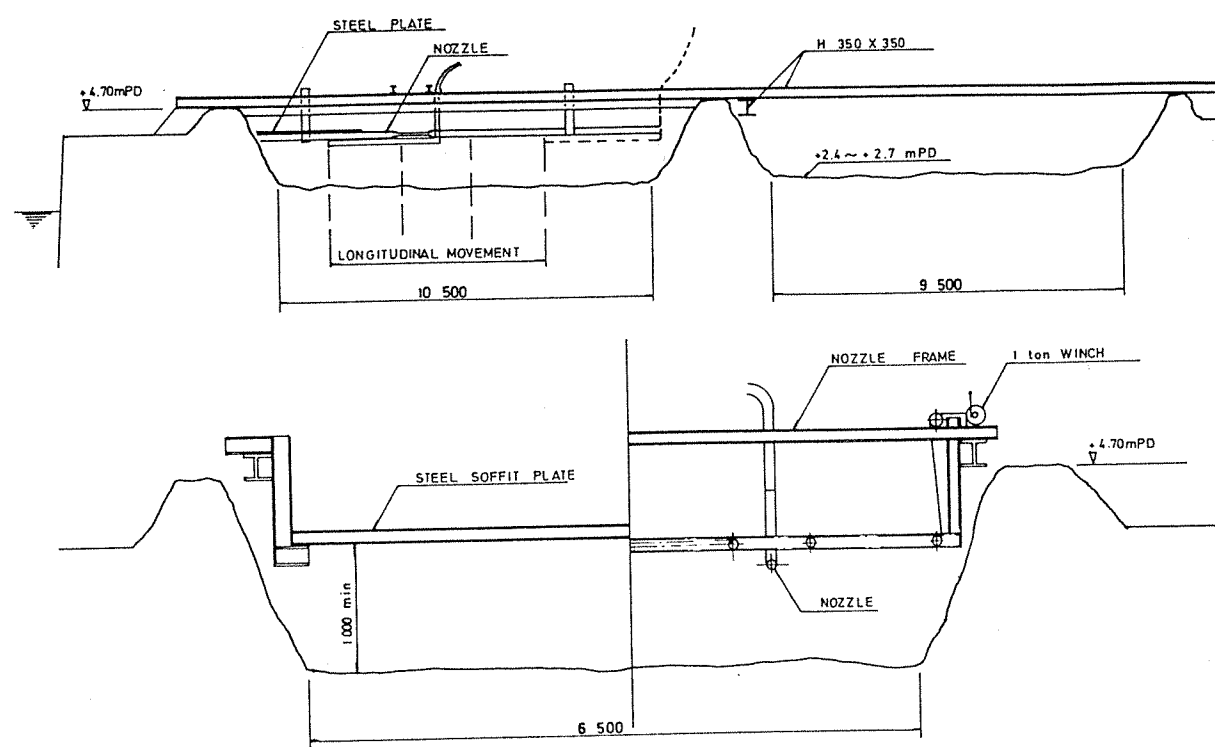


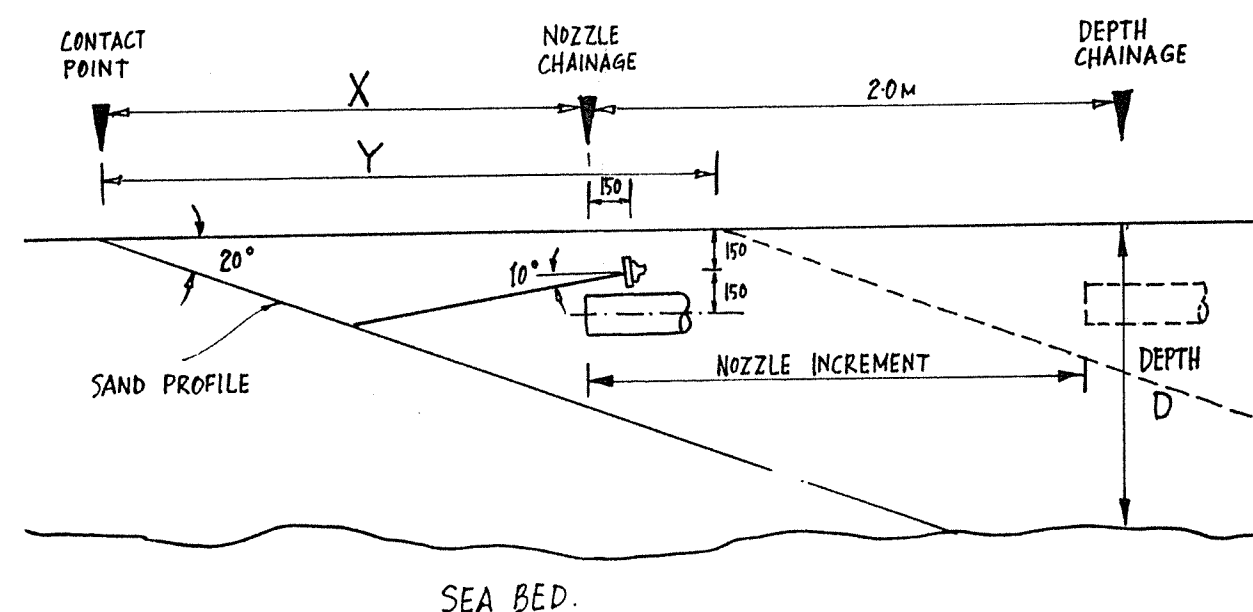
Figure 6. Sections Through Test Tank

- (b) The top surface of the sand is in contact with the surface representing the tunnel unit invert.
- (c) The area of contact between sand and the surface representing the tunnel unit invert is at least 80% of the total area.

Kumagai Gumi have extensive laboratory facilities in their Toyokawa works in Japan and they decided to conduct a series of large scale tests there. The set up of the tank and equipment is shown in Figures 5 and 6.

The experiments clearly demonstrated that the system is capable of achieving the minimum requirements needed to support the immersed tube tunnel without inducing any overstress in the structure of the units. Indeed nearly 100% of the top surface of the sand was in contact with the surface representing the tunnel invert, away from the edge effects caused by the walls of the tank.

However, the real problem lies with verification that the sand is in contact with an actual unit which is 122m long by 35.5m wide and 30m below the surface of Hong Kong harbour. The contractor used an echo sounder transducer mounted 1m offset from the delivery nozzle to "see" the build up of the sand as it was being deposited. Encouraging, but inconclusive, results were obtained during the Toyokawa experiments and it was decided that further tests would be necessary in Hong Kong to prove the system. The result of the tests was that approval for any one strip of sand would be given by the Resident Engineer's staff if the echo sounder reading complied with a deduced formula which is shown in Fig. 7.



$$X = \frac{L \sin 10^\circ + 0.15}{\tan 20^\circ} + L \cos 10^\circ - 0.15 \text{ metres}$$

$$= 1.46 L + 0.26$$

Figure 7. Formula for determining position of sand face

It should be emphasized that the values shown in the formula for angle of repose and for nozzle increment are extremely conservative. This is to ensure 100% overlap for subsequent 2m strips and give a very large margin for error.

Sand characteristics

Designers of all immersed tube tunnels that are to be founded on a placed in-situ bed of sand specify that a series of large scale tests be carried out before operations commence. This is necessary because sand, equipment and personnel are different for every tunnel. Worldwide much testing has been carried out but the results are not readily available because they have a commercial value to the organization conducting the experiments. However, much general information has been published in papers such as this one and it can be deduced that a whole spectrum of sand types has been tested for adequacy of sand foundations. No matter if the sand is fine or coarse, well graded or single grain size they all have one thing in common: they are capable of being mixed with water and pumped under the right conditions to produce a suitable foundation. This is not surprising to those who are familiar with cutter suction dredgers which can pump a wide range of materials from silt to rock to form reclamations. It demonstrates a basic law of nature that sand particles will be carried along with the pumping water when the velocity is above a critical velocity and they will settle when the velocity drops below this figure.

In Toyokawa a number of insitu and laboratory tests were carried out to determine the properties of the sand. The average values of the laboratory tests carried out on the sand before and after placing are shown in the table below. The particle size distribution complied with BS 882 1983 Grading limit M for fine aggregate for concrete.

Test Item	Before placing	After placing
Uniformity coefficient U_c	5.6	4.0
Curvature coefficient U_c	0.9	0.91
Specific gravity G_s	2.71	2.71
Water content $W(\%)$	6.0	18.1
Wet unit weight (g/cm^3)	1.49	1.94
Dry unit weight (g/cm^3)	1.41	1.64
Particles smaller than 0.15mm (%)	3.98	0.94
D_{10} (mm)	0.19	0.35

Perhaps the most interesting result here is that the percentage of particles smaller than 0.15mm decreased from nearly 4% to less than 1%. These fine particles moved along with the pumping water to collect in the corner of the test tank. This indicates that one of the main qualities required of the sand is that the content of particles less than 0.15mm should be kept as small as possible. This is partly an economic thing in that the fine particles are wastage in that they will travel with the pumping water and escape at the free edges of the system. Also, there is a possibility that, if the amount is excessive, a silt wave can build up causing a pocket of unsuitable matter which will have to be removed by airlifting before further placing sand.

Swedish penetrometer tests were carried out by inserting the probe through holes in the steel soffit plate at 21 locations. The average equivalent N-value was 1.3. Plate bearing tests were also carried out and the load/settlement characteristics were obtained.

The normal working load under a tunnel unit after backfilling is about 2 tonnes/ m^2 and the anticipated settlement of the sand layer is about 15mm. In some areas the sub-soil alluvium is also very soft and the first tunnel unit is being set 60mm higher than the theoretical finished level to allow for the anticipated combined settlements. There is a laying tolerance of + and -30mm to allow for differential settlement across the joint between any two units. After backfilling is complete, shear connections are made across the joints which will permit relative horizontal movement but no relative vertical movement between adjacent units.

Sources of sand

As has been mentioned before, the sandplacing system is capable of placing a satisfactory foundation of virtually any type of sand. The contractor was given a free choice to propose any sand complying with the particle distribution curves of BS 882 1983 grading limits M and C fine aggregate for concrete. The proviso being that further large scale tests of the selected sand must be carried out on site in Hong Kong to determine the pumping characteristics. The contractor investigated sands from 5 different sources.

Firstly a medium grained river sand from the Pearl River eastern delta area in Dongguan province was proposed. A site visit was undertaken by travelling to Whampoa and from there a four hour journey by river boat to the dredging site. The method of working the borrow area was typical of the way of working throughout the eastern delta area. A 200mm suction dredger with maximum dig depth of 7m raised the sand into a settlement hopper from there it was moved by chain bucket and conveyor to small barges. These barges were self propelled and were only capable of carrying about 200 tonnes of sand because the water depth in the eastern delta restricted boats to a maximum draught of 1.5m. These small barges travelled to Tai Ping on the Pearl estuary where the sand was transhipped to larger dumb barges for transportation to Hong Kong.

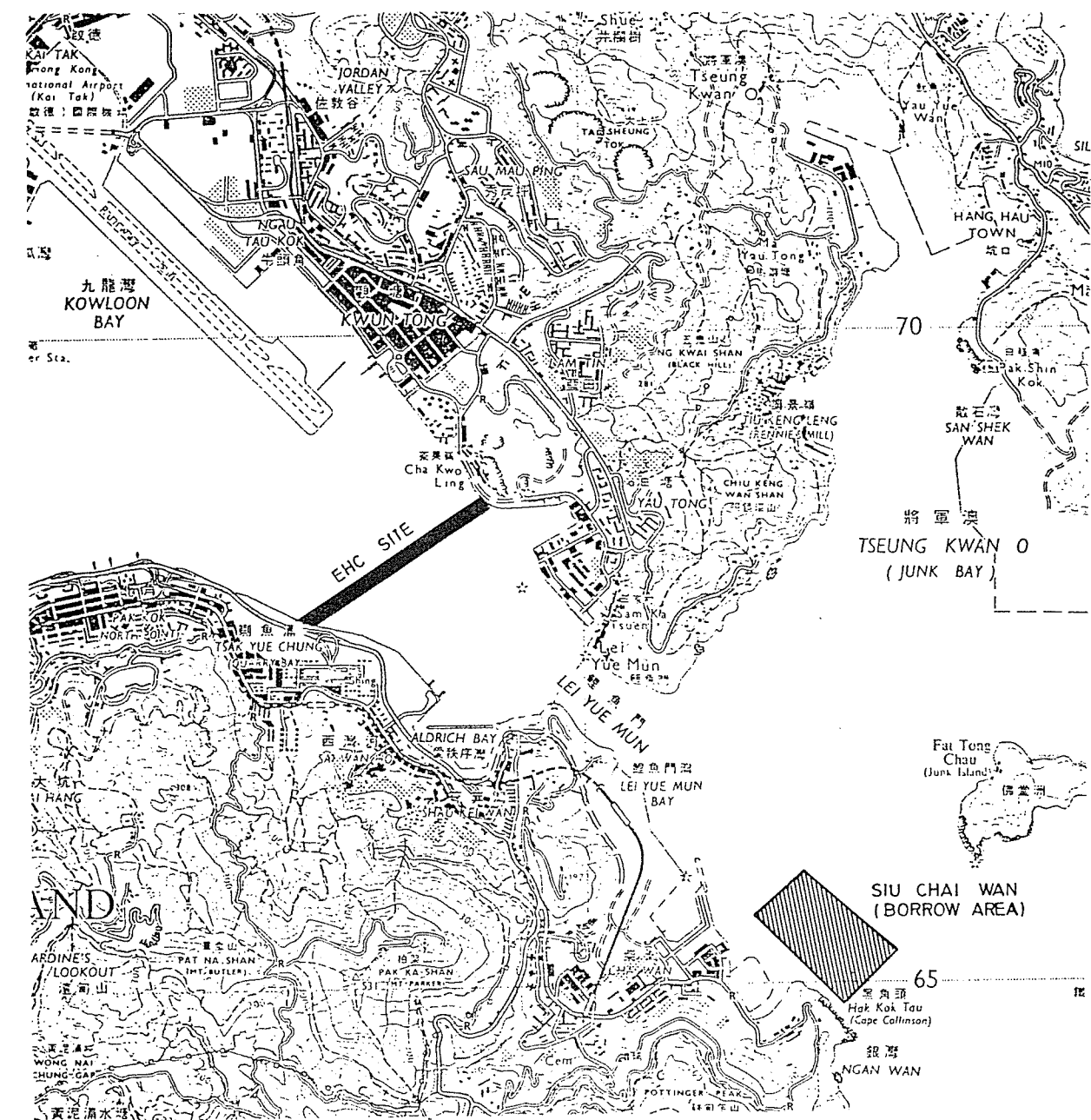


Figure 8. Site location plan

Secondly a marine sand from the borders of Guangdong and Fukien provinces in the Peoples Republic of China was proposed. This site visit involved a flight to Xiamen and then a 6 hour journey overland to the borrow area. This source had an abundant supply of very consistent medium grained sand. The site was well established and was already supplying a high quality silica sand for a new float glass plant recently commissioned in Shanghai. The site organization for dredging, washing, loading and transporting the sand was good. The barges were self propelled and the estimated sailing time to the Eastern Harbour Crossing site was 8 hours.

Crushed rock fines from Lamma quarry, alluvial sand dredged from the trench for the Eastern Harbour Crossing and marine sand from a borrow area at Sui Chai Wan were also proposed. The contractor finally decided on the Sui Chai Wan source for economic and logistic reasons. The contractor has his own dredging equipment and the borrow area is less than 3 km from the tunnel site and this made it clearly the cheapest source (see figure 8). Furthermore, dredging could take place as and when required to meet the demand of sand placing. Sand from Peoples Republic of China would have had to be stockpiled and double handled to guarantee an uninterrupted supply. After final large scale testing approval was given to use the sand from Sui Chai Wan and dredging has already started.

Conclusion

The theoretical total quantity of sand required for the project is small, being only in the order of 150,000m³. However, it is important that the supply of the sand is uninterrupted as subsequent tunnel units cannot be positioned until the previous unit has been supported on its bed of sand. This, together with the fact that it was the cheapest source, made Siu Chai Wan the obvious choice as the borrow area for supplying sand.

Acknowledgements

The Author wishes to thank Kumagai Gumi Company Limited and EHC Project Management Company Limited for their permission to publish this paper.

Environmental implications of exploiting marine sand

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SUMMARY The nature of the sediment which is to be exploited as a fill material for reclamation, and of any associated marine mud, is important in determining the likely environmental impact of the operation. The major areas of potential concern are the physical impact of fine sediment suspended in the water column, or distributed over adjacent areas of the seabed, and the release of soluble material and of bacteria from the disturbed sediment. Dredging procedures are also critical in determining the impact, and controls such as silt curtains may be needed if "dirty" methods are to be used in sensitive areas.

Until recently, marine sand deposits have rarely been used in Hong Kong. However the experience of two major projects has shown that exploitation is possible without any serious adverse effects, and full recovery of the dredged area is expected to occur in one or two years.

Introduction

Dredging submarine sand deposits to win fill for reclamation is a process which is immediately destructive to a portion of the marine environment. It is likely to be done on a grand scale: for example the land formation for the proposed new town of Tin Shui Wai in the north-western New Territories of Hong Kong needs 24 x 10⁶ m³ of sand. The target is usually a fairly coarse grained material, free from the fine silt and clay fraction which tends to be organic-rich and associated with anthropogenic pollution. However, the wanted material may be overlain by, or intermingled with more polluted marine muds. Environmental problems may occur in the extraction, transport, and placement of the fill, and in the disposal of unsuitable material.

In the past, marine sand has been little used for reclamation in Hong Kong. There are two apparent reasons for this. The first is the ready availability of sources of rock, and decomposed rock, on land, as compared with the lack of proven resources of marine sand. The second is the desire on the part of planning authorities to get double benefit in terms of developable land, by exploiting platforms cut from the hills for extracting fill as well as the land reclaimed from the sea. With the increasing scarcity of usable sources of fill on land, it has become necessary in this decade to find alternative sources. The search for fill for the Tin Shui Wai project, beginning in 1980, identified various possible sources in the Pearl River estuary and in Deep Bay (Dutton, 1987). The formation of the new Container Terminal 6, using marine fill, has been undertaken

during 1987. Increasing interest in the use of marine fill sources has led to increasing exploration for them, using geological models (Arthurton, 1986), and this has been matched by increasing attention to the environmental impact of their exploitation.

Internationally, there has been much more concern about the disposal of surficial dredged spoil than about the impact of dredging for reclamation purposes. In the United States, for example, most of the $300 \times 10^6 \text{ m}^3$ of sediment dredged each year is classed as routine maintenance intended to remove deposits of surficial sediments. It amounts to 88% of the total waste load dumped in the sea by the U.S., and in several areas is the dominant mechanism for transporting sediments from the continent to the oceans (National Research Council, 1985). Nevertheless, there is a considerable body of information relevant to the extraction of fill. Both of the major current projects in Hong Kong have been extensively investigated. It is the purpose of this paper to review the causes of the impact of dredging on the environment, in terms of the nature of the sediment and the release of material into the water column. Possible controls on the dredging procedures that cause this are considered. The actual and expected impacts of local projects are reported. In conclusion, the standards which dredging projects need to comply with are presented. In many cases marine sources of fill are more acceptable from the point of view of environmental management than are the available alternatives.

Sediment as an environmental material

From the point of view of environmental management, we have to look at near shore marine sediment as essentially two components. The first can be called deep sediment. This means that it has been in place long enough to be unaffected by anthropogenic pollution. The second is surficial sediment, which is typical of present day sedimentation, and is therefore susceptible to pollution (National Research Council, 1985).

Dredging for port maintenance is usually concerned only with the surficial sediments. Pollution of surficial sediments in a port or an industrialised estuary may be very heavy. Typically, the contamination will be indicated by increased concentrations of oil and grease, trace metals, and persistent organic chemicals of industrial origin such as polychlorinated biphenyls (PCBs) and polynuclear aromatic hydrocarbons (PAHs). Bacteria of faecal origin are also likely to be found.

Deeper sediments, on the other hand, tend to have a composition which is little different from the average of crustal rocks in the drainage basin. In the case of Hong Kong, (but not necessarily of the neighbouring Pearl River Estuary as a whole) some of the material that is of interest for large scale fill comes into this category. Arthurton (1986) described the local Quaternary deposits as generally consisting of a blanket of Holocene marine mud, up to 20 m thick, resting on late Pleistocene alluvial deposits up to 40 m thick. The deposition

of marine mud began with a rise in sea level about 8,000 years ago (Dutton, 1987).

Regardless of whether surficial sediment or the underlying alluvium is the target material to be removed, some disturbance of the surficial sediments is inevitable. It is therefore of importance to consider their origin and the spacial variations in their pollution. In an environment such as Hong Kong the origins of the surficial sediment are diverse. They include erosion of the catchment areas due to natural processes of rainfall and runoff, often exacerbated by human activities. For example it has been suggested that, in the north-eastern U.S.A., construction activities to support an increase of 1000 in the population can yield up to 1600 tonnes of sediment in a one to five year construction period (N.R.C., 1985). Sewage and industrial discharges are also significant contributors to the surficial sediments. In Hong Kong's Victoria Harbour, it is estimated that the amount of material removed annually in maintenance dredging is roughly equal to the amount of sewage sludge which is deposited on the seabed by the sewage outfalls and drains which serve the 3½ million people living in the area. A further factor is biological activity in the water column. In nutrient-enriched coastal waters, the growth and eventual decay of microscopic planktonic algae can result in a continual input of organic material into the surface sediments. This contributes to environmental degradation as bacterial activity stabilises the organic carbon, in the process depleting the oxygen concentration at the base of the water column. In addition, the organic rich sludge layer forms a reservoir of pollutant. It can do further harm if it is redistributed into the water column, either by natural storm conditions or by dredging.

The trace metal contamination of Hong Kong's surficial marine deposits has been investigated by Yim and Fung (1981). They reported the variations in eight elements, calcium, copper, iron, manganese, zinc, chromium, arsenic and lead. Chromium is a good indicator of industrial pollution, while copper, lead, and especially zinc (because of its use in soaps and cosmetics) indicate the impact of urban pollution generally. Arsenic may be associated with agricultural pesticides used in the Pearl River catchment. The highest concentrations of chromium were found in Victoria Harbour, especially its eastern end, and in Junk Bay, with further high values around Tsing Yi and off Castle Peak. Copper and zinc, as expected, showed highest values in Victoria Harbour. Lead was also concentrated in Victoria Harbour, especially the western part near Stonecutters Island. High lead values were found north of Lantau Island, and this was also where the highest arsenic values occurred. The importance of this work is in indicating where special care may be needed to prevent pollution by the mobilisation of surficial sediments during dredging. Two key target areas, north of Lantau and south of Ma Wan, are outside the most contaminated areas but by no means get a clean bill of health. South of Victoria Harbour, few problems of pollution are expected, despite the existence of a designated spoil dumping ground south of Cheung Chau.

The impact of dredging

Marine dredging inevitably removes the benthic organisms completely from the works area. The mechanical impact is such that few, if any, survive. In addition to this direct effect, there are four aspects of the impact of dredging on the marine environment to be considered. They are

- . the effect of inert sediment in the water column
- . the settlement of sediment in areas around the operation
- . the release of non-inert material to the water column
- . lowering the seabed

As with any industrial activity, the air pollution and noise effects must not be neglected. However, they are not considered in detail in this paper because they exert their impact outside the marine environment which is its main focus.

Suspended sediment

Mechanical dredging of moderately fine-grained cohesive sediments has been reported to cause suspended sediment to exceed background levels by more than two orders of magnitude (N.R.C., 1985). Increased sediment suspended in the plume downstream of a dredging operation reduces light penetration into the water column. This reduces primary productivity, the production of plant material from inorganic chemicals by photosynthesis. The availability of dissolved oxygen to marine life is reduced, since this is a by-product of photosynthesis. At the same level of insolation, the temperature of more turbid water is higher, reducing the saturation concentration of dissolved oxygen and potentially further decreasing the availability of oxygen. In a further effect, the reduced primary production reduces the uptake of nutrients from the water column, exacerbating any problems of nutrient release considered below.

Within the water column, the practical effect of these effects is difficult, if not impossible, to assess. Free swimming organisms avoid the areas affected. This may disturb migratory fish, but the main problem in Hong Kong is to ensure that sensitive spawning grounds and mariculture zones are not affected. The duration of the effect is short, and the area affected is small, so with these reservations it is considered that the water column impact of inert sediment is negligible.

Settling sediment

The area around the dredging works will be subject to a continual rain of sediment settling to the seabed. In the extreme, this may bury benthic organisms. Burial to a depth of at least 200 mm, or persistent suspended solids concentrations in excess of 2000 mg/l, would be lethal to most benthic organisms (N.R.C., 1985). Such rates of deposition would occur only very near to the dredging operation. The area affected would be negligible as compared with the area of total removal of benthos.

At lower rates of sedimentation, the sub-lethal effects may be more significant. Filter feeding organisms, including scallops, mussels, and the oysters which are of great importance in relation to the Tin Shui Wai project, are most at risk. They obtain their nutrition by passing large volumes of water over their specially adapted gills, which filter out food particles. The presence of high concentrations of inert solids, which have to be cleared at the expense of wasted energy, can slow their growth. A number of investigations have shown that these organisms can tolerate concentrations in the range of 100 to 1000 mg/l for short times. The critical rate of burial of Deep Bay oysters was estimated to be 50 mm/year, while a rate of less than 5 mm/year was thought to be negligible (Bowler, 1985).

The nett result is that, while sensitive species such as the filter feeders may be eliminated from the most impacted areas, animals which can tolerate the increased sedimentation will survive. They may even proliferate, due to the reduced pressure of inter-specific competition. An area of total benthic defaunation, surrounded by an area of reduced species diversity, is produced.

Recolonization of the affected area by benthic organisms starts immediately. The first colonizers to settle on the dredged seabed are free-swimming opportunistic animals, such as fish, shrimps, crabs and, to a lesser degree, molluscs and worms. Resettlement by animals with a sedentary mode of life, such as burrowing worms and bivalve molluscs, would be slower. It would depend on the presence of planktonic larvae and spats in the vicinity. In Hong Kong's subtropical waters, conditions are relatively favourable. It is estimated that benthic communities in dredged areas not otherwise under stress can recover to their prior condition in one or two years.

Non-inert material

The impact of non-inert material released to the water column has been described by Binnie and Partners and Shankland Cox (1985) as part of the environmental impact assessment of the land formation for the Tin Shui Wai development.

Chemical conditions in the estuarine environment cause metals and most chemical pollutants to become associated with the sediment phase. They may be effectively immobilised in the bottom sediments even though they are in soluble forms. Disturbance of the sediment, as in dredging, can release these substances to the water column. Ammoniacal nitrogen, iron and manganese are readily released. Nickel, chromium, copper, lead, zinc, arsenic, phosphates and silicates are released less readily. Cadmium can be released under certain conditions, but mercury is not normally released except in very small quantity by biomethylation. The danger of most of these substances is that, if they are present in significant amounts in the water column, they may be incorporated into living organisms and accumulate in the food chain, to the detriment of the ecosystem and ultimately of the human population.

Apart from these potentially toxic substances, the release of chemically reduced compounds to the water column will exert an immediate oxygen demand. This may cause serious short term damage to the ecosystem. The inorganic compounds of iron and manganese would be oxidised first, followed by sulphides. Biological oxidation of soluble organic compounds would exert a slower oxygen demand.

Nitrogen, phosphorus and silicate would be released to the water column, and so become available to promote algal growth. This is the converse of the effect of suspended sediment, which, by limiting light penetration, tends to inhibit algal growth. However, as noted above, the effects of suspended sediment are relatively localised; on the other hand nutrients may remain in the water column long enough to have a significant effect on algal growth.

Complex organic substances such as pesticide residues and PCBs are likely to be released into the water column if they are present in the sediments. As with the trace metals they would become a problem if accumulated through the food chain.

Most bacteria of significance for human disease are killed by the marine environment. The presence in sediment of *E. coli* indicates recent (or continuing) faecal pollution. The release of pathogens into the water column is likely to become a hazard through the contamination of organisms used for food. Again, the filter-feeding bivalves, especially oysters, are most at risk. Pathogens to organisms lower in the ecosystem than man may also be released by dredging and concentrated through the food chain.

Seabed lowering

Alterations to the bathymetry affect water movement in a complex way. Hollows in the seabed can be areas of reduced mixing, where anoxic conditions occur. The lower seabed may receive significantly less light, and thus be unsuitable for the benthos which formerly occupied it. However, alterations to the pattern of mixing due to the local deepening relocate the area of maximum sediment deposition, tending to restore equilibrium at the pre-dredging sediment profile.

Pollution controls for dredging operations

It is not the purpose of this paper to review dredging methods, as they are well covered elsewhere. Instead, the available methods for predicting and controlling the main sources of water pollution in dredging operations are considered.

Sediment is released into the water column in the action of dredging itself, whether hydraulic or mechanical methods are used, in placing the fill, and in disposing of unusable material. Some dredging methods, for example the trailing suction hopper dredger, intrinsically distribute less sediment into the water than others. On the other hand, overflowing of the hoppers to

wash out fines releases an enormous quantity, up to 20% of the total sediment dredged, into the water.

Among the sensitive uses of marine waters which are to be protected against the adverse effects of dredging are marine fish culture areas, oyster beds, intensive fishing areas, fish spawning grounds, bathing and other recreational waters, and sites of special scientific interest.

Predictive models

Mathematical modelling can be used to predict the effects of dredging and the extent of its impact. Comparing the predicted sediment plumes caused by dredging at different sites and by different methods of operation can show the least damaging option for a particular project. The need for control or mitigation procedures can be evaluated where sensitive sites are threatened. Mathematical modelling can also be used to investigate the relationship between changes in seabed geometry, circulation, and water quality. This may be very demanding of data. A sediment deposition model, called SPOIL, developed for the Tin Shui Wai project, has been described by Bowler (1985).

Operational techniques

Careful operation and supervision, good design and selection of equipment and efficient, and well planned procedures can minimise the release of sediment into the water. The Tin Shui Wai environmental impact assessment, previously cited, identified a number of points at which control can be exercised in each method of working and each phase of operation.

Physical barriers

The most common kind of barrier used to prevent the spread of suspended sediment is the silt curtain. Silt curtains are extensively used in Japan. A silt curtain is an impervious floating barrier that extends vertically from the water surface to a specified water depth. It creates an enclosure where some of the finer material may flocculate and settle, but does not retain water and its load of suspended sediment indefinitely. Hatano and Abe (1986) have described how induced downward flows inside the silt curtain increase the rate of settlement, but the so-called jet flow beneath the curtain may cause some re-suspension. Silt curtains are expensive to buy, install and use (the latter because they restrict the operational area severely) and would only be required in exceptional circumstances.

Regulatory control procedures

Special contract conditions, in addition to compliance with existing environmental protection legislation, can be used to control and minimise the impact of dredging. Prediction of the impact, as noted above, is critical to identifying the controls

to be applied in a particular case. "Good operational practice" would normally be specified as a minimum requirement. Restrictions on the timing of the operation might be imposed to protect sensitive uses of some areas, especially during the fish spawning season. Prohibition of overflow and the use of silt curtains could be required in extreme cases. Arrangements for the safe disposal of surplus and unsuitable material at designated spoil grounds would have to be specified. Monitoring of the impact of the project would be used to indicate compliance, and a "go/no-go" approach, whereby acceptable standards must be achieved before progressing to the next phase of works, could be used in appropriate circumstances.

Water quality monitoring

Environmental monitoring is essential, both before and during dredging operations. Water quality and biological determinations may be required. The purpose is to establish the baseline water quality and to identify any changes induced by the dredging. Adequate baseline data for most purposes in Hong Kong is available from the Environmental Protection Department's monitoring programme. As with most major industrial operations, the engineer responsible for the project is likely to be required to carry out self-monitoring, and report the results to the E.P.D. The E.P.D. itself will carry out check monitoring and special purpose investigations. In addition to measurements of suspended solids and turbidity at various points, nutrients, oxygen demand, and other determinations may be necessary.

Major dredging projects in Hong Kong

As explained above, Hong Kong's experience of major dredging projects for marine fill is limited to two projects, Tin Shui Wai and Container Terminal 6. Both of these projects have been well described elsewhere, and this paper only reviews their impacts on the marine environment.

Tin Shui Wai

Land formation for the proposed new town of Tin Shui Wai has been the subject of a thorough environmental impact assessment carried out by Binnie and Partners and Shankland Cox. Due to the timing of the project, there is as yet little knowledge of its impact in practice. However, the predictive work reported by Bowler (1985) is instructive.

The main cause for concern in this project is the impact of the dredging operation on the oyster beds in Deep Bay, which are close to the sources of fill which have been identified. Accordingly the predictive model, SPOIL, was developed to show the extent of harmful deposition of sediment. It was found that, with various plausible sediment release rates, one of the exploitable sand sources in outer Deep Bay could be used without having an unacceptable effect on the oyster beds.

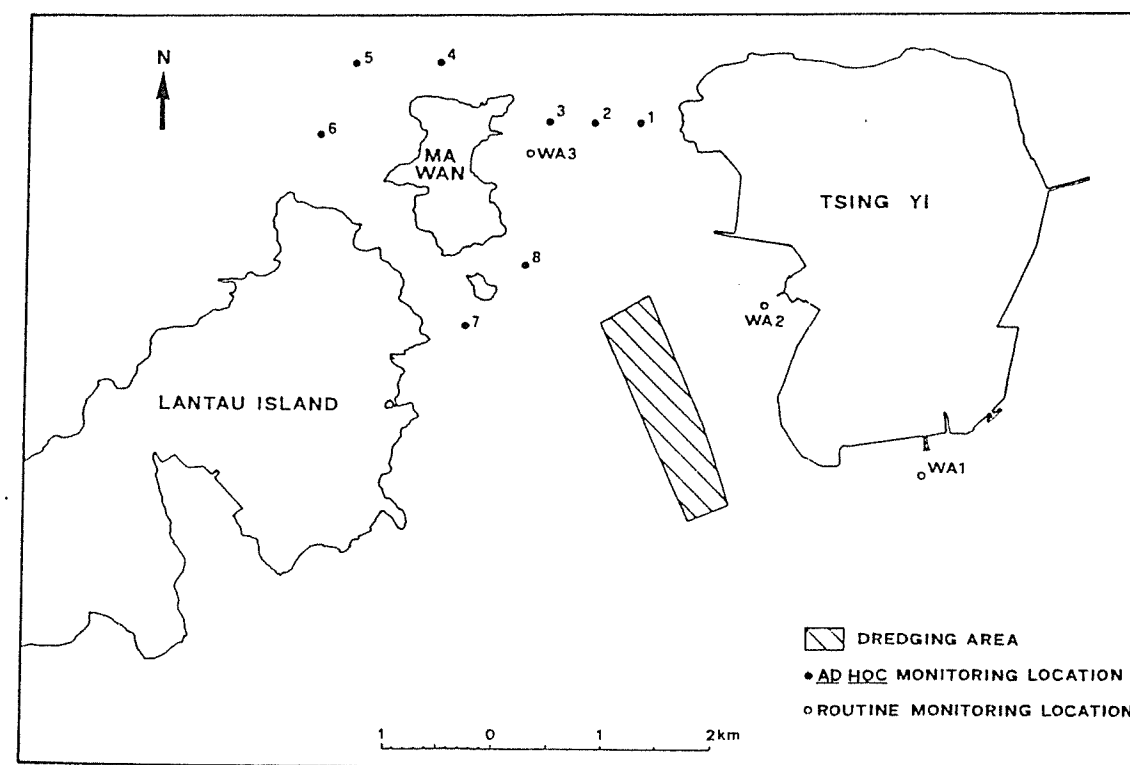
The rate of release of soluble pollutants to the water column was also investigated. Comparison of the levels of sediment contamination with the data of Yim and Fung (1981) (who unfortunately did not cover Deep Bay in their work) showed that of the metals tested, chromium levels were generally higher in Deep Bay while arsenic levels were lower. The others, calcium, copper, iron, lead, manganese, and zinc, were similar. These data were used in a box model to determine the likely increases in concentrations in the water resulting from the dredging. It was found that the only significant increase would be in manganese, which is not regarded as toxic to biota.

Bacteria derived from sewage were found in the sediments. However it was estimated that their release to the water column would not be a problem.

Container Terminal 6

The problems facing this project are rather different from those of the Tin Shui Wai project. Two areas of marine sand were considered, one off northern Lantau and the other south of Ma Wan. Neither is near to any important shellfishery. Mariculture at Ma Wan is the nearest sensitive marine use. A major concern, however, was that the release of biodegradable carbon compounds and of nutrients would exacerbate the general levels of marine pollution in or near to Victoria Harbour.

Figure 1 Sampling points near the dredging site at Ma Wan



No mathematical model was available to elucidate the impact of this project on the marine environment, and the project's time scale did not permit one to be developed. This unfortunate omission should be rectified before future large scale projects are carried out. The procedure adopted was to investigate the sediments themselves to find out whether they were polluted to a significant extent, and whether the rates of release of material to the water column were likely to be significant.

Sediment samples from the areas under investigation were provided by the engineer for the project, Maunsell Consultants. Soluble nutrients were determined on the filtrates of 20% weight/volume suspensions of the sediment in 3.4% sodium chloride solution. This is similar to the 'elutriate test' which was adopted by the U. S. EPA in 1973 in an attempt to identify contaminated sediment. Five representative metals, cadmium, chromium, copper, lead and zinc were also determined. The results are summarised in tables 1 and 2, along with comparable metal data from a severely polluted site in Hong Kong and from unpolluted sites overseas.

Table 1 Concentrations of trace metals in sediments from C.T.6 dredging areas and comparative data

	Container Term. 6		Kowloon Bay (Hong Kong)		Southern California	N.W. Persian Gulf
	North Lantau	Ma Wan	(1)	(2)	(3)	(3)
Cadmium	<.2	<.2	2 - 6	.43	.26	
Chromium	.73 - 7.3	.10 - 5.9	120 - 780	25.5	-	
Copper	2.5 - 6.2	.19 - 3.7	480 - 1000	9.02	2.59	
Lead	3.9 - 15.	.22 - 9.5	110 - 180	10.5	3.55	
Zinc	8.7 - 53.	1.3 - 3.9	330 - 810	44.4	13.74	

Data are reported as mg/kg dry weight.

(1) EPA survey, 1985

(2) Katz and Kaplan (1981)

(3) Al-Hashimi and Salman (1985)

In the data of table 1, the Ma Wan site shows consistently lower concentrations of the metals tested than the north Lantau site. However both sites were free from gross anthropogenic pollution, and no problems arising from the release of metals into the water column were anticipated. The data on nutrients, however, suggest that this aspect may be more problematical. The nutrient results are shown in table 2.

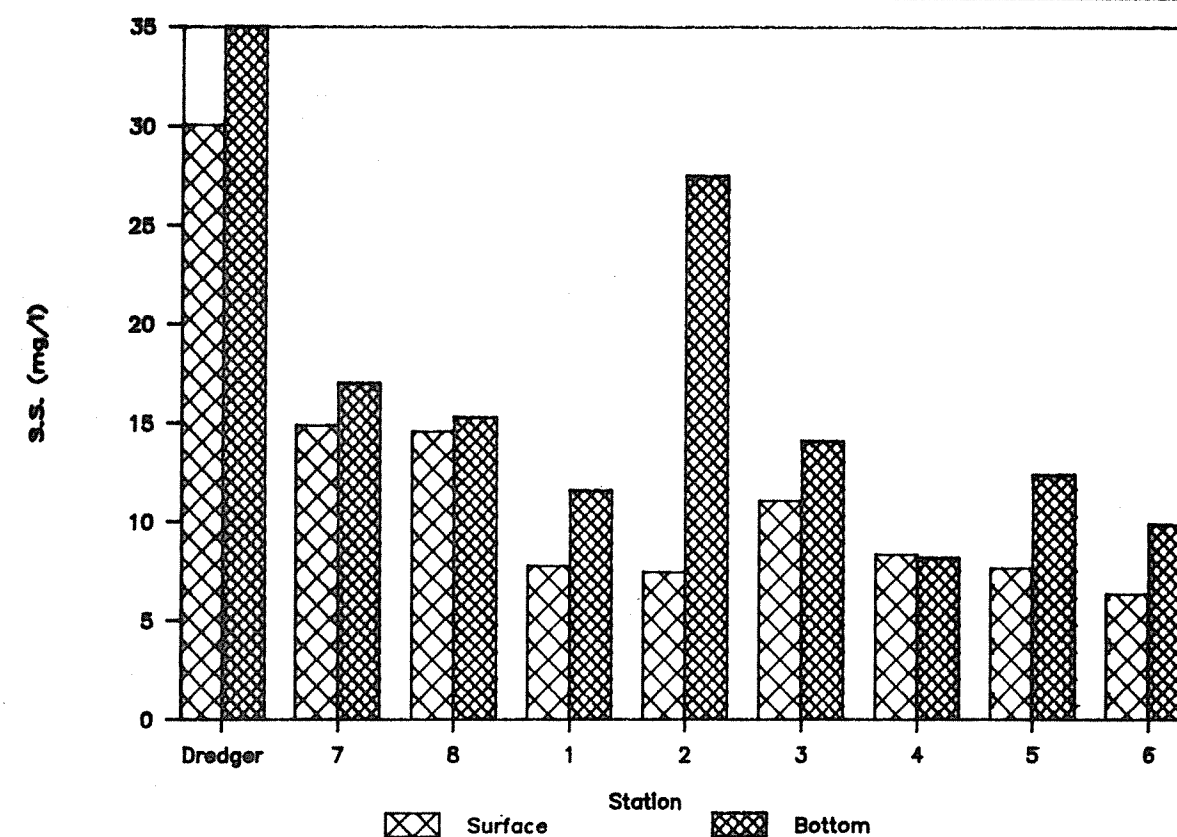
From the nutrient data, rates of release were estimated, on the assumption that 15 to 20% of the silt clay fraction would be lost to the aqueous phase, with a total extraction rate of 500 000 m³/month. The total nitrogen loading for the north Lantau area was estimated to be 9700 kg/month, and the total phosphorus loading 770 kg/month. These figures were judged to be tolerable. For the site south of Ma Wan the corresponding figures were 80 000 kg/month total nitrogen and 47 000 kg/month.

Table 2 Elutriate nutrient data for C.T.6 areas

	Ammonia N	Organic N	Nitrite N	Nitrate N	Ortho- P	Total P	Silica
North Lantau							
minimum	.58	1.7	.13	.029	.16	.48	5.4
maximum	9.1	19.	1.1	7.4	.35	1.3	43
mean	3.03	6.97	.38	1.63	.26	.95	30.7
Ma Wan							
minimum	.23	4.5	.005	.026	.19	4.4	7.1
maximum	3.3	220	.081	.20	.57	260	17
mean	1.39	85.4	.028	.101	.38	57.8	10.6

Data are reported as mg/kg wet weight

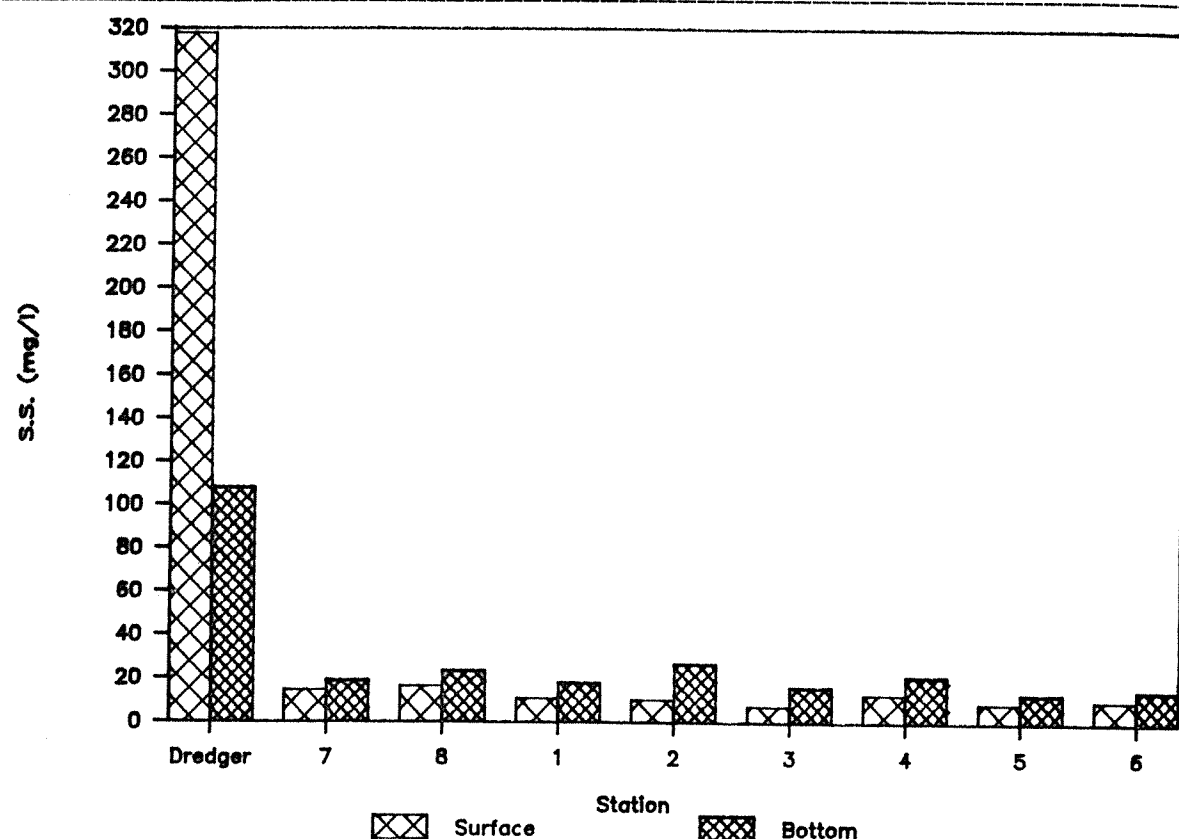
Figure 2 Results of sediment sampling during dredging



Model testing would have been beneficial at this stage. In the absence of a model, it was concluded that the work could proceed without restriction, but that monitoring would be needed to anticipate any serious problems.

In the event, the site south of Ma Wan was selected. Most of the dredging was carried out between April and August, 1987, using three trailing suction hopper dredgers. Daily water monitoring in the immediate vicinity of the dredging area was

Figure 3 Results of sediment sampling during hopper overflow.

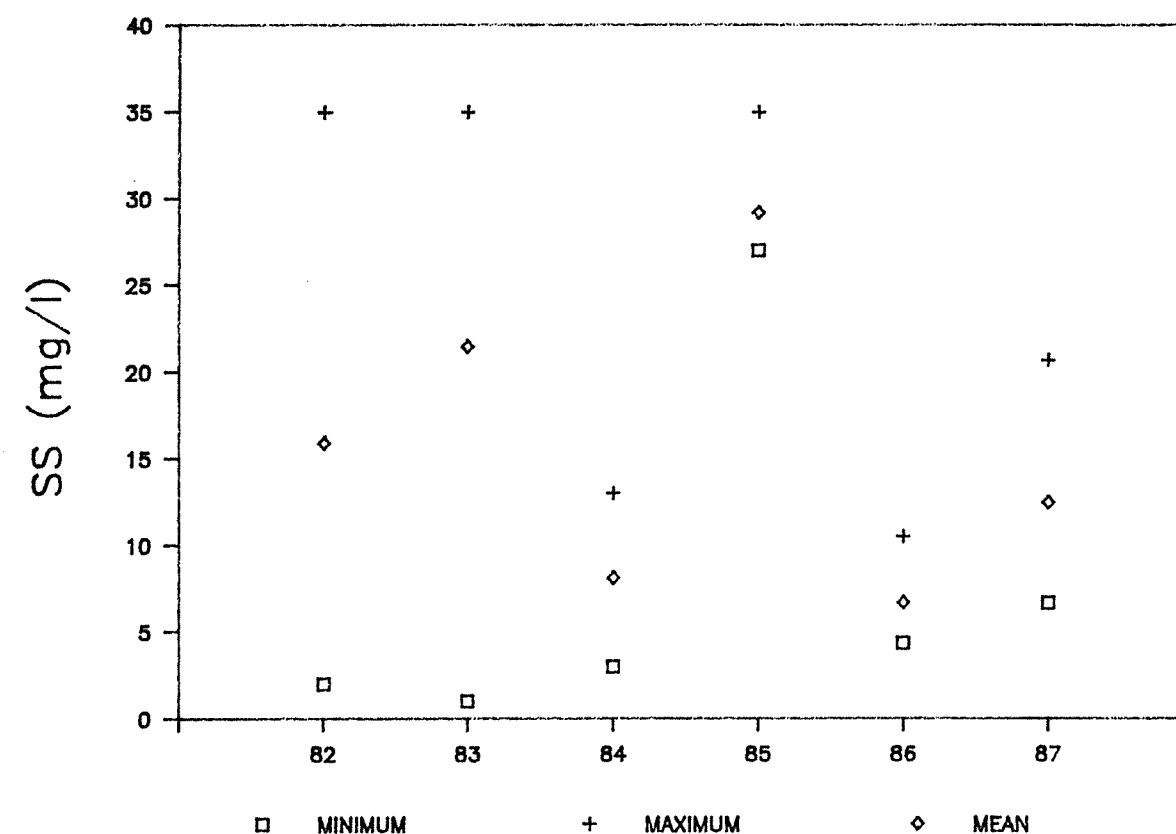


undertaken by the engineer responsible. Meanwhile the Environmental Protection Department undertook studies to determine the effect, if any, the work had near the mariculture zone at Ma Wan and at nearby routine monitoring stations. The location of the monitoring points in relation to the works area is shown in figure 1.

The first objective was to determine whether the levels of suspended solids levels in the vicinity of the mariculture zone at Ma Wan were raised to an unacceptable degree. Samples were taken at the locations numbered 1 to 8 on figure 1, and in the immediate vicinity of the dredger during the operation, at such times on the rising tide that the current flow was from the dredger towards the sampling site. Locations 7 and 8 were close to the dredging site, about 1000 to 1500 m from the site limit. Locations 1, 2 and 3 were each about 2000 m north of the site. Locations 4, 5 and 6 were near to the mariculture zone west of Ma Wan, and were about 3500 m from the limit of the dredging site.

The results of sampling during the dredging operation are shown in figure 2. Compared with the average background concentration of about 16 mg/l, even the concentration close to the dredger is not significantly elevated. Only one sampling occasion is represented in this data; no resources could be spared for further investigation where there was clearly no evidence of a problem. However, when the trailing suction

Figure 4 Suspended solids (mg/l) at routine sampling points before and during dredging



hopper dredger started its overflow to wash out fine grained material at the end of each dredging cycle, there was a sharp increase in the level of suspended solids near the dredger. A visible plume of sediment developed. Even this plume tended to settle rapidly, and as shown in figure 3, there was still no effect in the vicinity of the sensitive mariculture site. In this case the data is the mean of three sampling occasions.

The second objective was to determine whether there was evidence of increased pollution in the vicinity of the operation that could be attributed to it. This was determined by reference to the levels of suspended solids, biochemical oxygen demand (BOD), and nutrients determined as total Kjeldhal nitrogen (TKN) and total phosphorus (TP), at the three routine sampling points nearest to the dredging area. As shown in figure 1, the locations of the sampling points, WA1 to WA3, are not ideal in relation to the site. They were left unchanged for compatibility with the long term sampling record.

The results obtained during the main dredging operation, April to August 1987, are shown in comparison with the corresponding period in each of the five previous years, in figures 4 to 7. The results for the three locations were lumped together to ensure that a reasonable number - at least six - samples were included in each year group. None of the four

Figure 5 B O D (mg/l) at routine sampling points

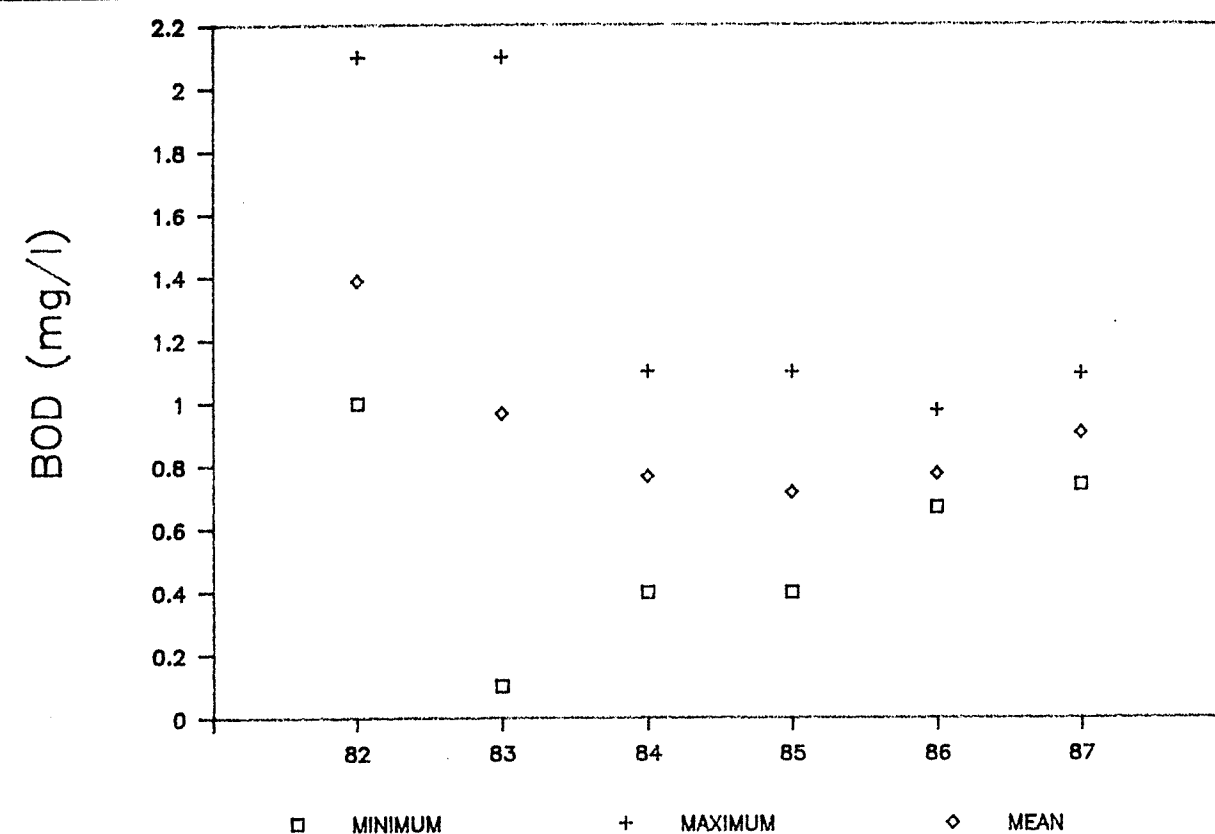


Figure 6 T K N (mg/l) at routine sampling points

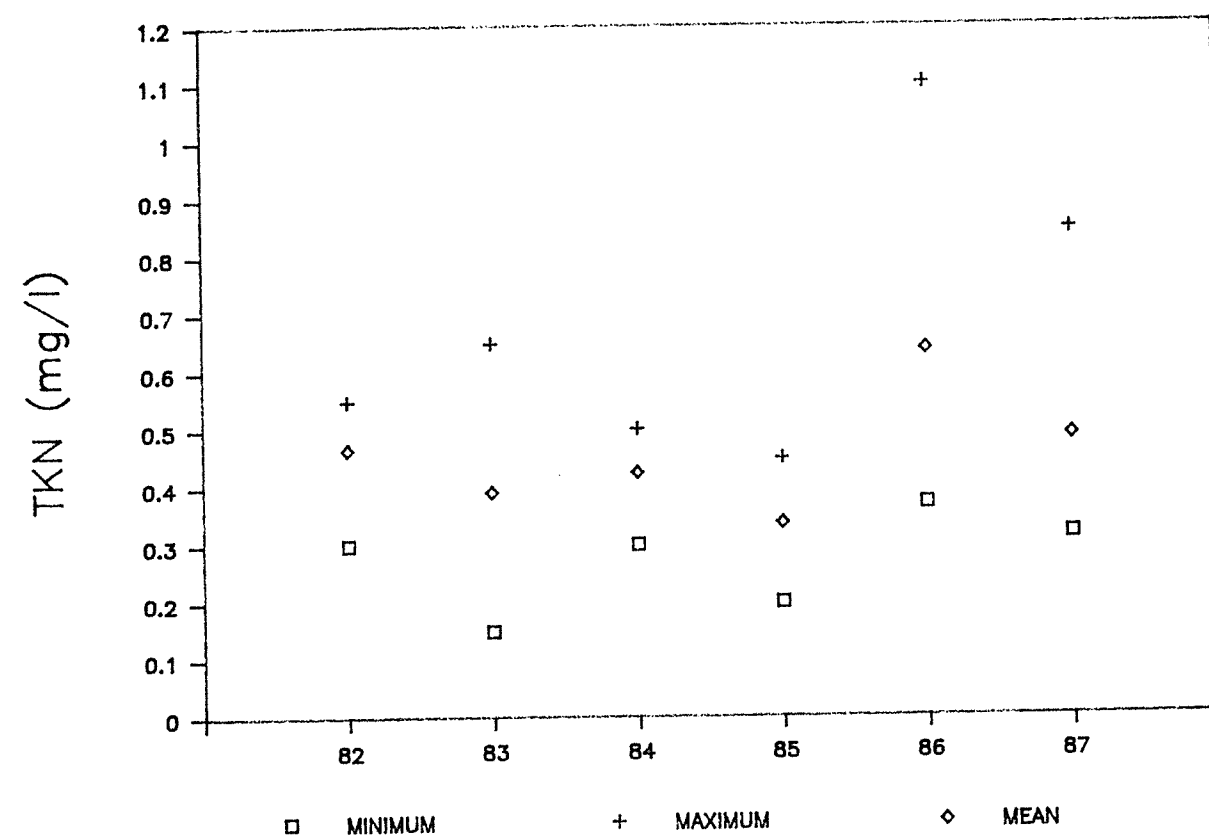
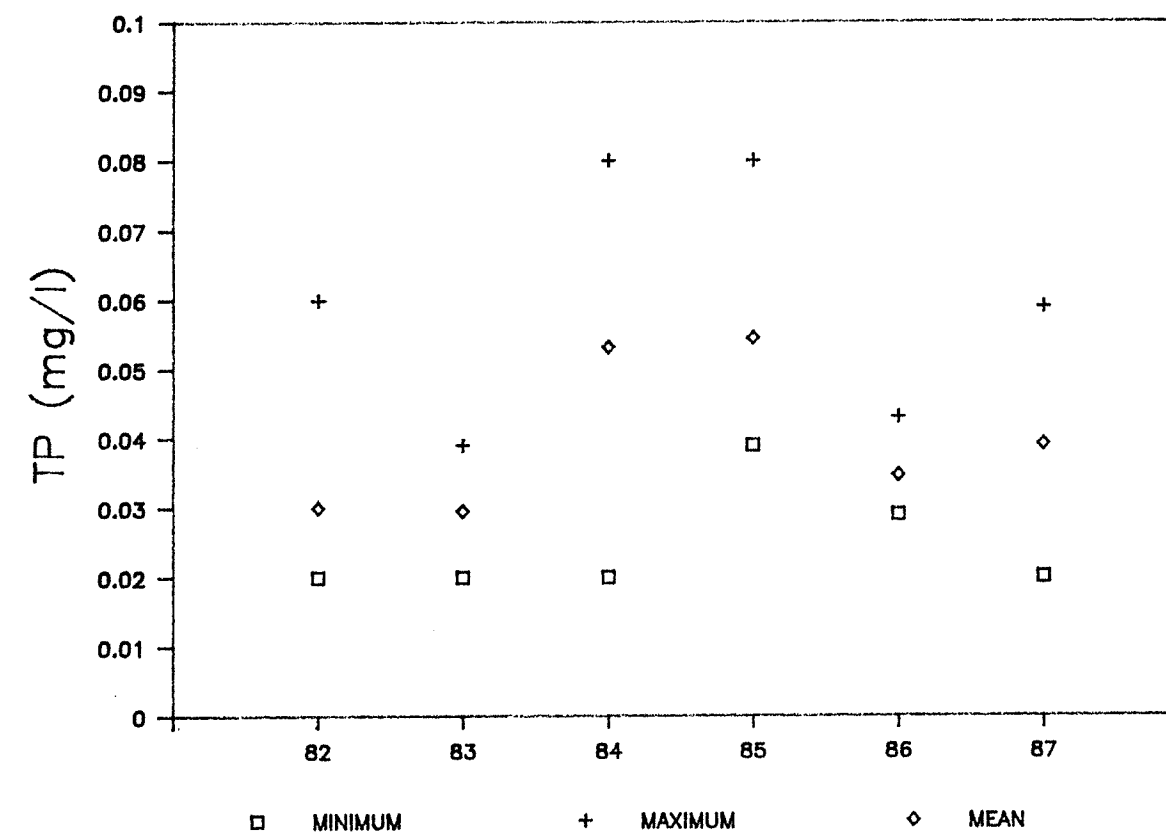


Figure 7 Total phosphorus (mg/l) at routine sampling points before and during dredging



determinands show a clear trend in the time period shown, and the results for the period of dredging are within the range of previous results. The data were tested by the variance ratio, F test, and Student's t test, which showed that in none of these cases was there evidence of a significant difference (at the 5% confidence level) during the dredging operations.

The conclusions obtained by monitoring are supported by the paucity of complaints about the operation. A few claims made by fishermen at an early stage in the work were not substantiated, and no claim has been sustained since.

Conclusions

Dredging can have a severe impact on the marine environment, by the immediate destruction of the biota of the works area, by the distribution of sediment loads in the vicinity of the area, and by the release of contaminants from the sediment into the water column. The extent of the impact can be predicted successfully by mathematical modelling techniques, and this certainly is essential in cases where sensitive marine uses, such as shellfish culture, exist in the vicinity of the works area. Where such uses are remote from the works, as in the case of the dredging for Container Terminal 6, there is no evidence that severe or long term environmental impacts are to be expected. Compared with the disruption, air pollution, noise, and permanent damage to the landscape that can be caused by extracting fill from sources on land, marine fill from such sites is certainly to be preferred.

Assessment of dredging proposals by the Environmental Protection Department will be aimed at ensuring that the criterion of adequate separation from sensitive uses, in relation to the scale of the works, local hydraulic conditions, and the existing state of the environment, is maintained. In cases where adequate separation cannot be assured, on the basis of previous experience, additional baseline data may have to be acquired and mathematical modelling will be an essential pre-requisite. Depending on the results, restrictions on the operation, such as banning the overflow of hoppers and the imposition of silt curtains, may be required. Such cases are likely to occur in the vicinity of fish and shellfish culture areas and sites of special scientific interest, the actual distances depending on the extent of the works, and in any case in very sensitive water bodies such as inner Deep Bay and Tolo Harbour and Channel. "Good operational practice" will almost always be required, and the meaning of this can be spelt out in contract documents if necessary. Monitoring will be required in all significant cases.

Good environmental management requires the protection of all the beneficial uses of the sea. Despite the restrictions which are essential for this protection, the evidence available at the time of writing suggests that there are in Hong Kong many areas where marine sand can be safely exploited with minimal precautions.

Acknowledgements

The contributions made by the author's colleagues, especially Dr Paul K. S. Shin, to the preparation of this paper, are gratefully acknowledged.

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**Preliminary indications from the
Hong Kong Government's offshore sand search**

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SUMMARY The Geotechnical Control Office of the Hong Kong Government is carrying out an exploration for offshore sources of fill material for use in future reclamations. This search initially concentrated on locating deposits of buried alluvial sand and gravel in areas where the cover of marine mud is thin.

The central and western parts of the Territory have been surveyed by a high resolution boomer, on an approximately two kilometres grid. A target zone, south of Tsing Yi Island, has been drilled, and additional seismic profiling has been run on a 500 metres grid.

As a result of strong tidal flows, there is almost no marine mud in the target zone. The water depth is between 20 and 30 metres.

The geophysics and drilling have shown that over an area of four square kilometres, there are substantial deposits of clean alluvial sand and gravel, overlain by muddy, shelly marine sand. The bulk of the granular deposits lie between 25 and 55 metres below sea-level.

It seems probable that other deposits, in a similar geological setting, exist elsewhere in Hong Kong and along the southern China coast.

Introduction

As part of the Hong Kong Government's longterm planning, large areas of reclamation are currently being considered, to provide building land for the 1990's. Other large projects such as a new airport and further container terminals may also include substantial reclamations. The potential requirement for fill material for all these projects could be several hundred million cubic metres.

Traditionally, most of the fill for Hong Kong's urban reclamations has come from land borrow areas, with marine fill tending to be used in specific engineering projects such as Kai Tak Airport and Plover Cove Dam (Guilford, 1988). Small volumes of marine fill have been used regularly for bedding seawalls etc. A current use is described by Thomson (1988).

Recently, construction of Container Terminal 6 using modern dredging techniques has renewed interest in the use of marine sources of fill for major reclamations (Wragge-Morley, 1988).

The possible environmental advantages of using marine as opposed to land-derived material have also been considered (eg Holmes, 1988).

It is with this background, that the Urban Area Development Office of the Hong Kong Government commissioned the Geotechnical Control Office (GCO), to carry out exploration for Marine sources of fill. This

exploration programme is expected to be complete towards the end of 1988. This paper presents some preliminary indications from the GCO's work to date.

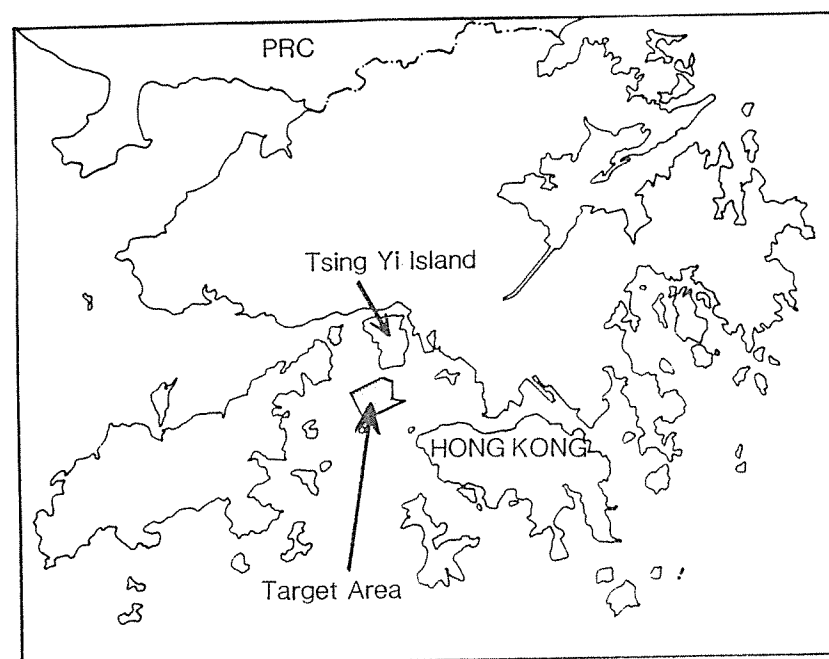


Figure 1 Keyplan showing the location of the sand and gravel deposit south of Tsing Yi Island, Hong Kong

Background to the exploration programme

Since suitable fill material is likely to be predominantly granular (eg Ford, 1988) the main thrust of the exploration programme has been directed towards locating substantial volumes of sand and gravel.

Prior to the current survey, there was very little information about sand and gravel in the offshore area of Hong Kong. Information that was available tended to be confined to near-coastal, engineering sites. Nevertheless, a model of the Quaternary geology has emerged in the past few years, particularly with the recent work in the GCO, by the Hong Kong Geological Survey (Bennett, 1984 ; Addison, 1986 ; Strange & Shaw, 1986; Geotechnical Control Office, 1986 ; Shaw 1987). The activities of the Marine Studies Group of the Geological Society of Hong Kong have also contributed to the understanding of the offshore deposits (Whiteside & Arthurton, 1986). The general offshore succession is now seen as Holocene marine deposits, which are predominantly mud, overlying Pleistocene alluvium.

Noteworthy among other, engineering-related investigations, and of great importance in the exploration for offshore sand and gravel, is the work of Dutton (1985, 1987) for Tin Shui Wai New Town in the north west New Territories of Hong Kong. His work on buried Pleistocene river channels, and Arthurton's (1985), study of tidal channels, considerably encouraged local interest in offshore sources of fill (Burnett, 1986). The geological model, as further developed by Arthurton (1987), was of key importance in the desk study for the GCO exploration programme. The Author's main conclusion in the desk study, was that the largest accessible sand deposits

are likely to be along buried Pleistocene river channels, in areas where recent tidal channels have prevented or restricted the deposition of marine mud.

At the same time as the geological desk study was underway, a complementary study was being carried out to identify non-geological constraints which might affect the selection of targets for detailed investigation. From this study, a maximum overburden of 10 metres of mud was adopted, initially at least, as a criterion for selecting targets for further, detailed investigation.

The administrative aspects were also being considered at this time because in Hong Kong, proposals for large marine dredging operations have to be publically advertised in The Hong Kong Government Gazette before permission to dredge is given (Government of Hong Kong, 1985) so that any objections may be made. Based on the desk study, two areas were selected for gazetting, (Government of Hong Kong, 1987) one of them, south of Tsing Yi Island. This latter area was selected because it was adjacent to the existing borrow area being used for Container Terminal 6, and also because it was an area where a present-day tidal channel probably coincided with a buried alluvial channel.

The exploration programme was planned as two phases. Firstly, as an overall reconnaissance, the area has been covered by a marine geophysical survey using an approximately 2kms grid of high resolution boomer traverses (Ridley Thomas et al, 1988.) Secondly, once potential targets have been identified, boreholes are drilled to determine the nature of the various seismic units, and a 500m grid of boomer traverses is run to more fully determine the shape and volume of the seismic units.

The findings of the reconnaissance survey in the central and western Territorial waters are described by Shaw (1988), and some specific aspects of the findings are discussed by Evans (1988). The preliminary results of the second stage survey on the most promising target to date, are presented below.

Target south of Tsing Yi Island - Seismic traverses

Selection of the target

The general area is shown on the keyplan, Figure 1. The reconnaissance geophysics shows an area to the south of Tsing Yi Island, where the marine mud thins out due to non-deposition.

Beneath the main tidal channel, the geophysical records show a buried, channel-like feature with steeply dipping reflectors. The geophysics traces also show an elongate, asymmetrical bank on the seabed in the centre of the present-day channel. The area was targeted for detailed investigation because of the possibility that these features indicated the presence of buried granular channel deposits overlain by a bank of sandy material.

Figure 2 shows the bathymetry of the target area in metres PD (Mean sea level is 1.23 mPD), the outline of the area gazetted for possible dredging, and the location of the marine borrow area used for Container Terminal 6. The figure also shows the lines defining where the mud cover is over 10 metres.

Although the geological deposits of interest are likely to extend beyond the gazetted area, the boundary of gazetting provided a convenient limit for the first part of the detailed stage of the investigation.

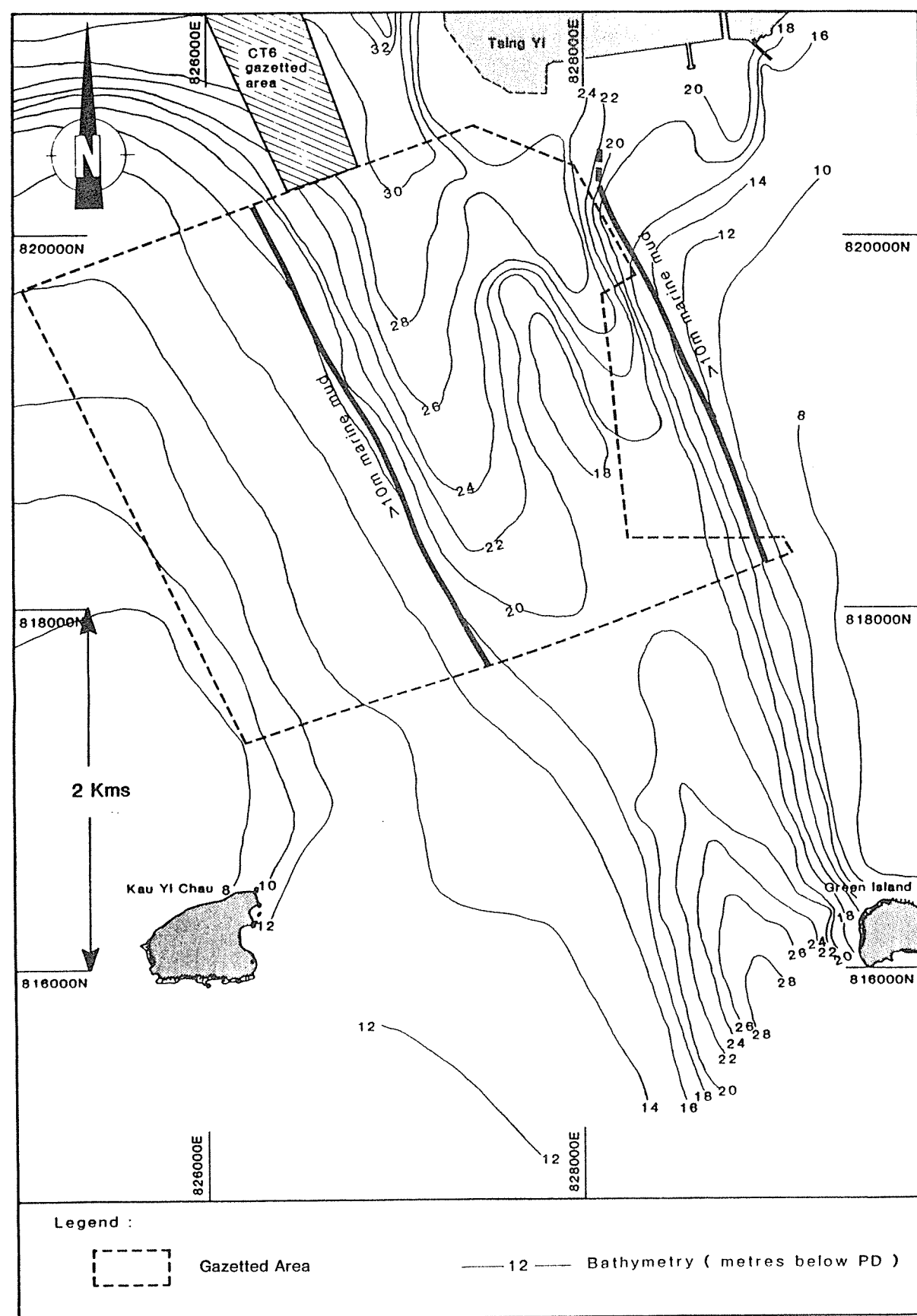


Figure 2 Plan showing the bathymetry south of Tsing Yi Island

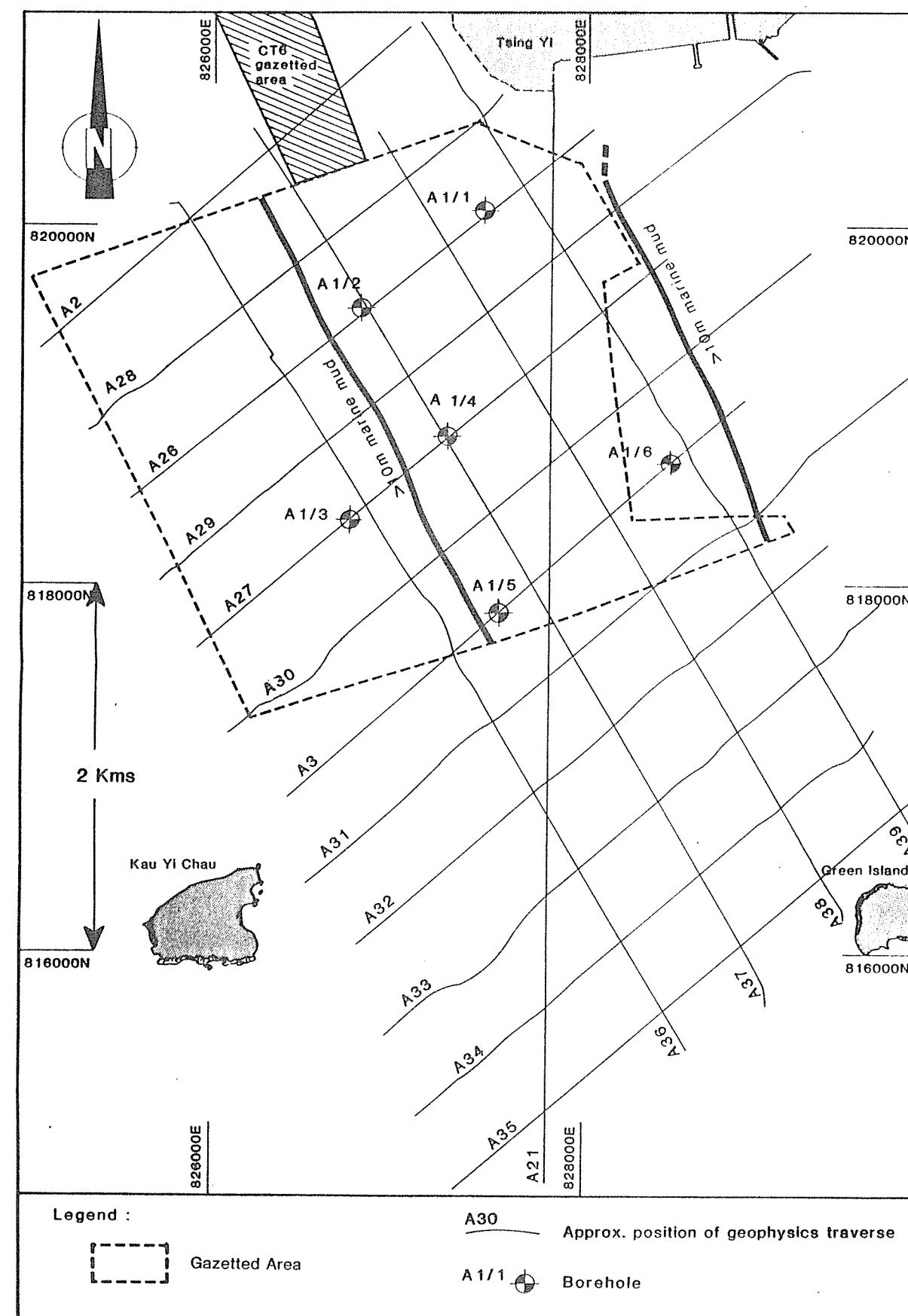


Figure 3 Plan showing the location of geophysics traverses and boreholes south of Tsing Yi Island.

Pattern of seismic units

The location of the seismic traverses is shown in Figure 3. The lines numbered up to A27 are part of the reconnaissance stage survey, and those from A28 onwards are part of the more detailed second stage investigation.

The first object of the investigation was to delineate the pattern of different seismic units. An individual assessment was made of each seismic traverse, and then the consistency of the identifications was checked by comparing intersecting traverses. One traverse has been selected to illustrate the pattern of seismic units. Figure 4a shows the seismic profile along line A27. Several different seismic units are clearly evident, and the main ones have been identified and numbered (i) to (vi), in Figure 4b. The fairly transparent uppermost unit, on the flanks of the channel, can be seen with its internal reflectors downlapping towards the tidal channel, indicating non-deposition (unit (i)).

The asymmetrical bank in the centre of the present-day tidal channel clearly has an internal structure which is conformable with its present shape (unit (ii)). This implies that it is a depositional rather than an erosional feature.

Beneath the feather edge of unit (i), is an internally stratified unit which rises eastwards, towards the seabed, and has the appearance of a shallow, truncated bank (unit (iii)). It is interesting to note that this shallow bank can be traced northwards on the other geophysics traces. Figure 5 is a copy of part of the geophysics traces A27 to A2. The truncated bank can be clearly seen to enlarge when followed northwards. This bank is apparently that which has been dredged for Container Terminal 6. This truncated, half-buried bank appears to be a moribund bank, such as described by Evans (1988). On traverse A27 this shallow truncated bank conformably overlies the well-layered infilling of a dish-shaped depression (unit (iv)).

At the south-west end of the traverse, the dissected surface of a poorly stratified unit is evident (unit (v)). The morphology of this surface is very similar to that identified in Victoria Harbour by Strange & Shaw (1986).

Buried beneath the present-day tidal channel is a large seismic unit with steeply dipping, sigmoidal-shaped reflectors, each of which can be traced upwards until it becomes horizontal (unit (vi)). The resulting composite unit is thus made up of a lower section of steeply dipping reflectors topped by a section of horizontally stratified reflectors (Figure 4b). This unit appears to be the lateral equivalent of unit (v).

An irregular, weak reflector, mostly made up of individual hyperbolic traces, is also identified in Figure 4, towards the base of the profile.

Target south of Tsing Yi Island - Borehole data

General

The locations of the six boreholes are shown in Figure 3. As shown in the Figure, the boreholes were located on seismic traverse lines in order to correlate the borehole data with the geophysics.

The boreholes were drilled by cable-tool percussion methods, with continuous, half-metre push tube samples being taken. The material collected with the bailer every half metre as the casing was advanced, was retained as a bag sample.

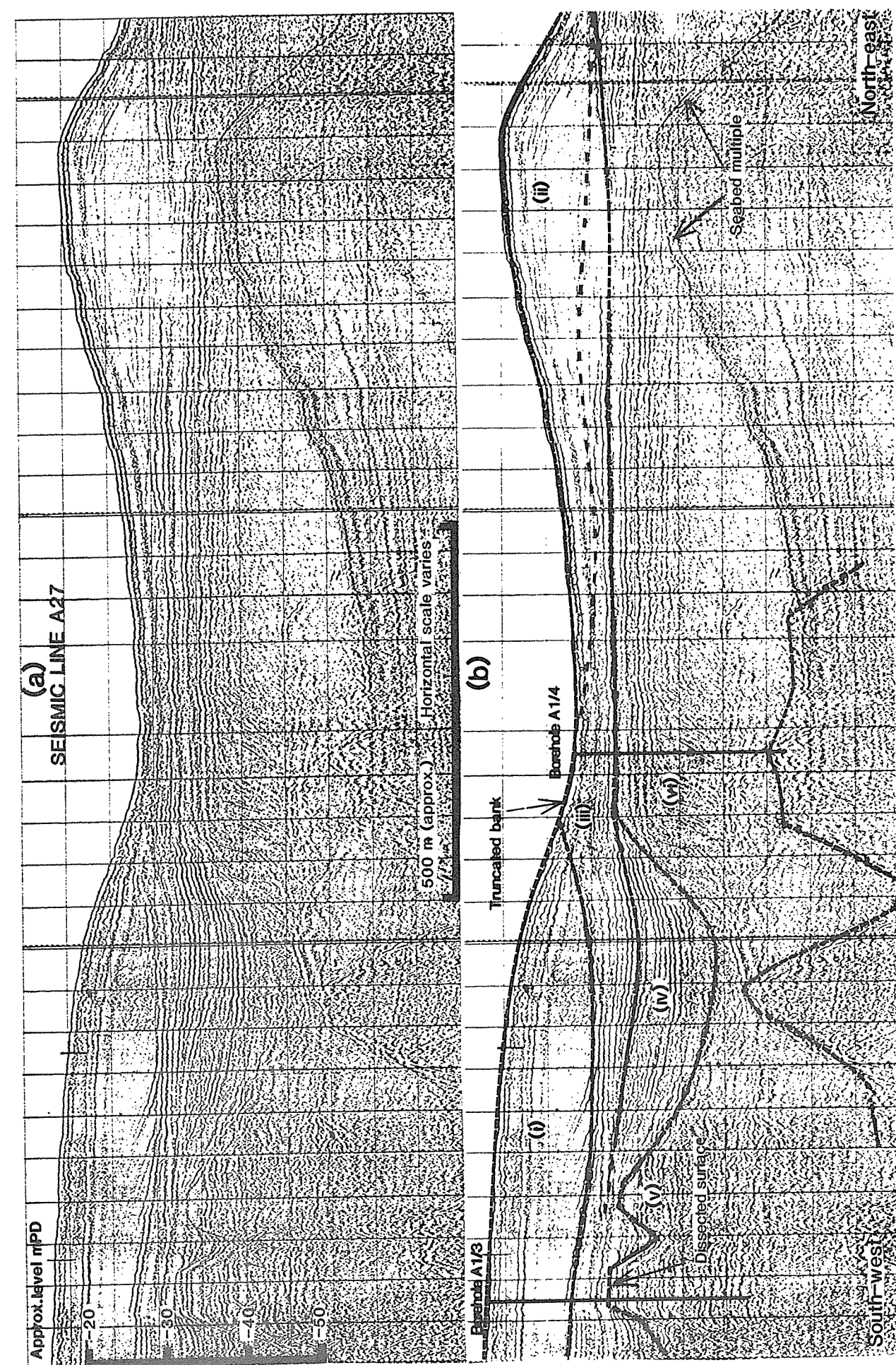


Figure 4 (a) Seismic line A27 (b) Identification of seismic units on line A27

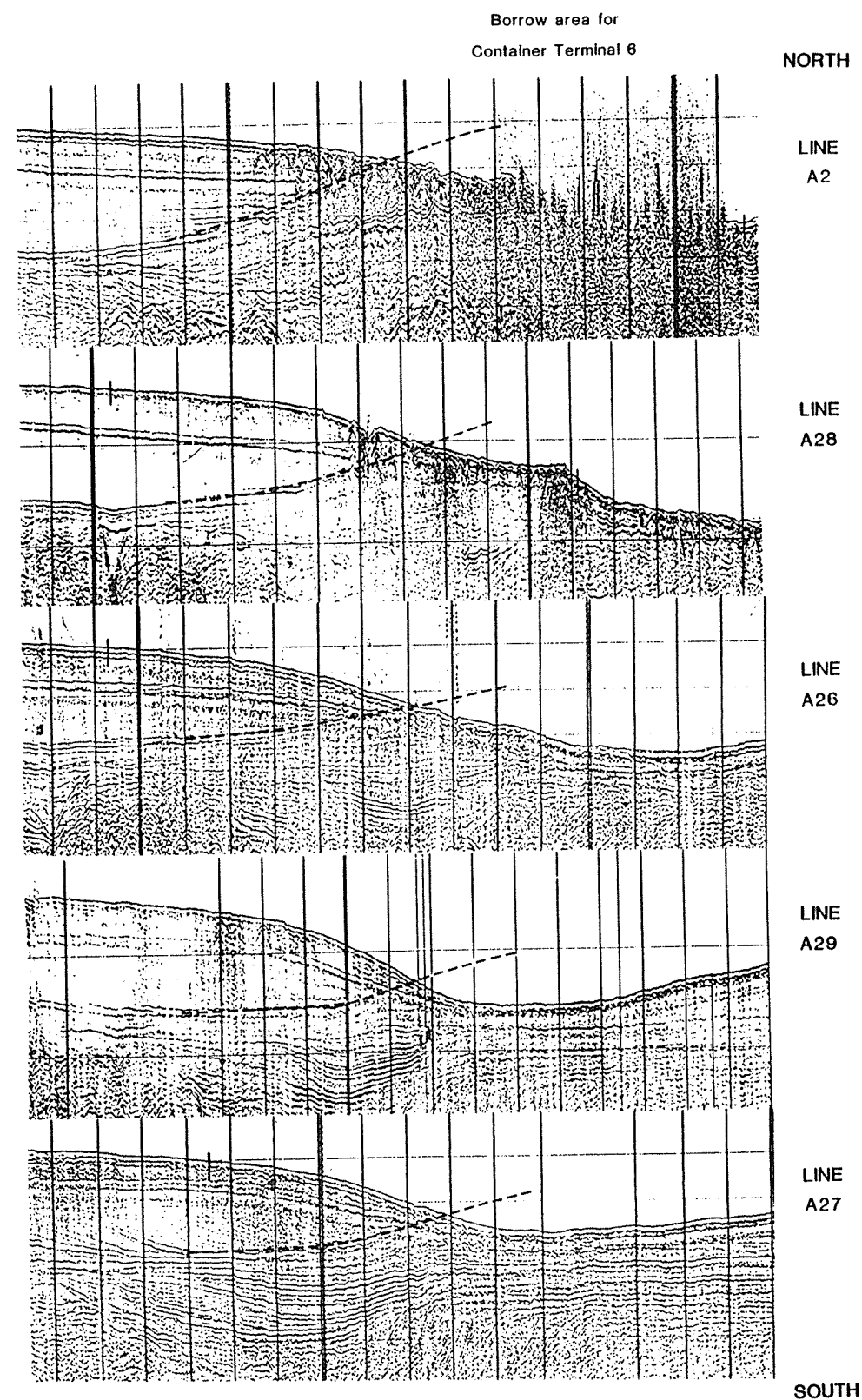


Figure 5 Parts of seismic profiles from A27 northwards to A2, showing the increasing size of the truncated marine sand bank

For simplicity, the sediments encountered have been divided into a few main types. This simplified subdivision is based on an examination of the bag samples and selected tube samples. In general, the extruded tube samples were found to contain similar material to the adjacent bag samples, in both fine and granular sediments. A summary of the sediments encountered is given in the synoptic logs in Figure 6. The main subdivisions and their broad characteristics are described below. It must be emphasised that the following descriptions apply at the borehole locations, and that the nature of the sediment may be different elsewhere.

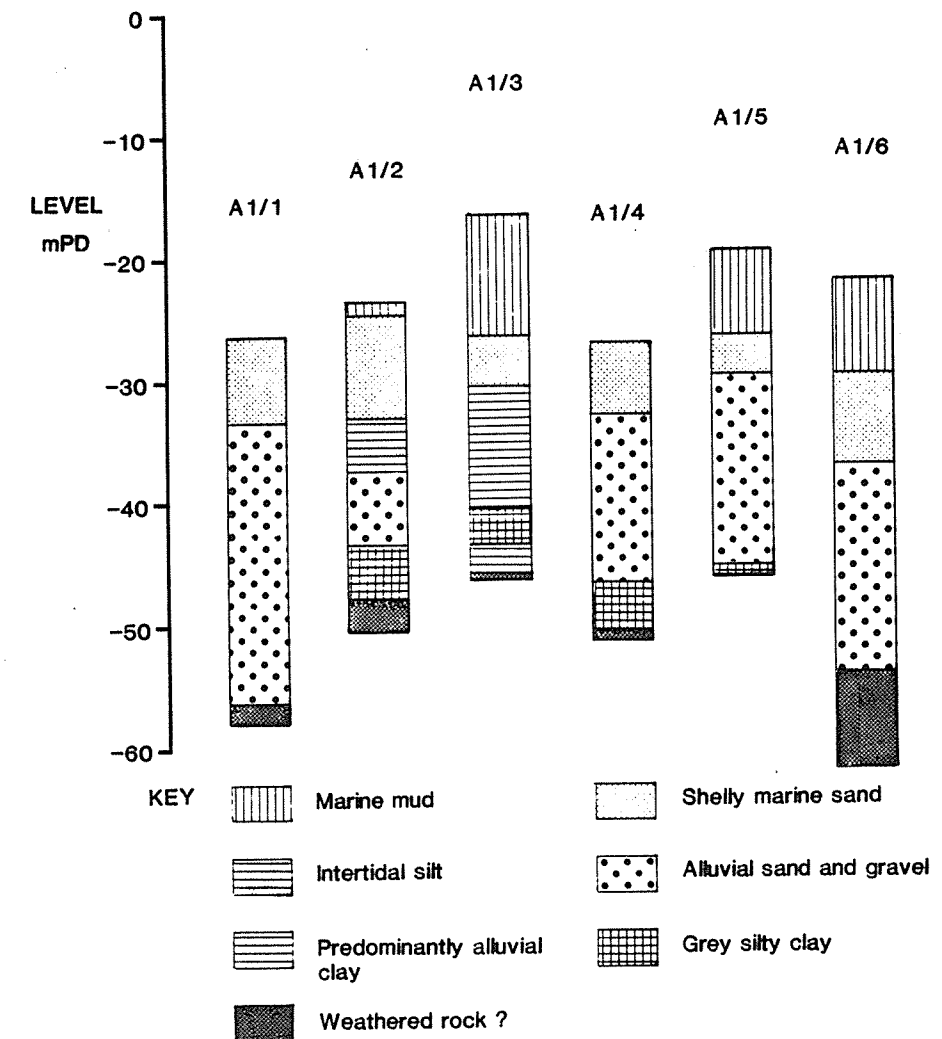


Figure 6 Synoptic borehole logs

Marine mud

The marine mud is typically a dark, greenish or bluish grey, slightly sandy, very silty clay or clayey silt. It is generally soft to very soft, and normally contains a significant number of shells, mostly bivalves.

Intact shells are common, but throughout, there are finely comminuted fragments.

Marine sand

The marine sand is generally a muddy fine sand with comminuted shell fragments. Medium to coarse shelly sand with occasional gravel also occurs, particularly at the very base of the marine deposits. The triangular plot in Figure 7 shows the typical content of fines, sand and gravel. The shell content varies considerably. Locally, for example in borehole A1/4, the granular component consists almost entirely of shell fragments. However, visual estimates suggest that a figure of about 10 - 20% of the total weight is more usual. The remainder of the sand fraction is essentially quartz. Grading curves and shell content measurements are presented by Carbray (1988). The grey colour of the sand is due to the fines.

Observations made on site at the marine borrow area being used for Container Terminal 6, suggest that the marine sand sampled south of Tsing Yi is similar material. For comparison, the triangular plot in Figure 7 also shows typical fines, sand and gravel content for the Container Terminal 6 borrow area material.

The Standard Penetration Test results (SPT by British Standards Institution, 1981) ranged from 0 to 51, with an average of 14.

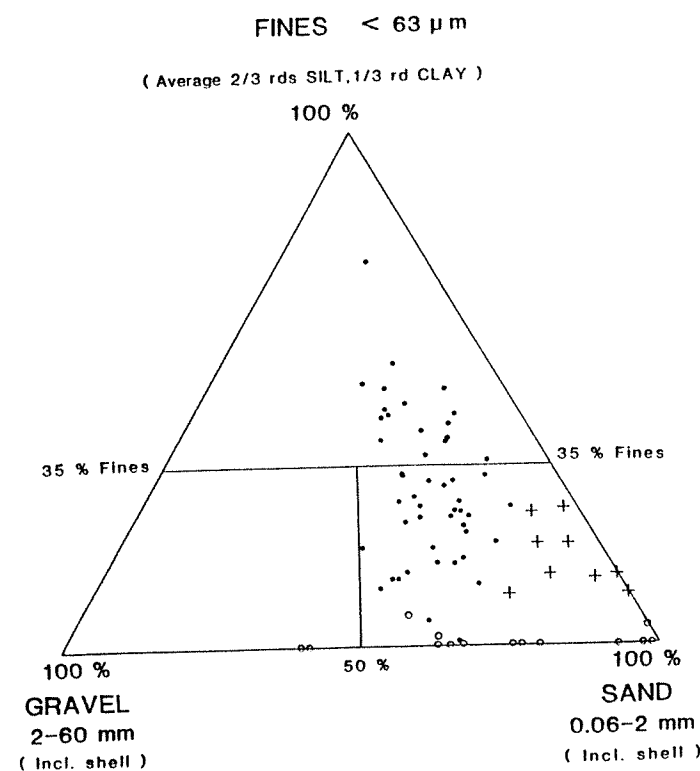


Figure 7 Triangular plot showing sand, gravel and fines content of various offshore sands. Dots represent the Container Terminal 6 borrow area material, crosses the marine sand south of Tsing Yi, and the circles the alluvial sand south of Tsing Yi.

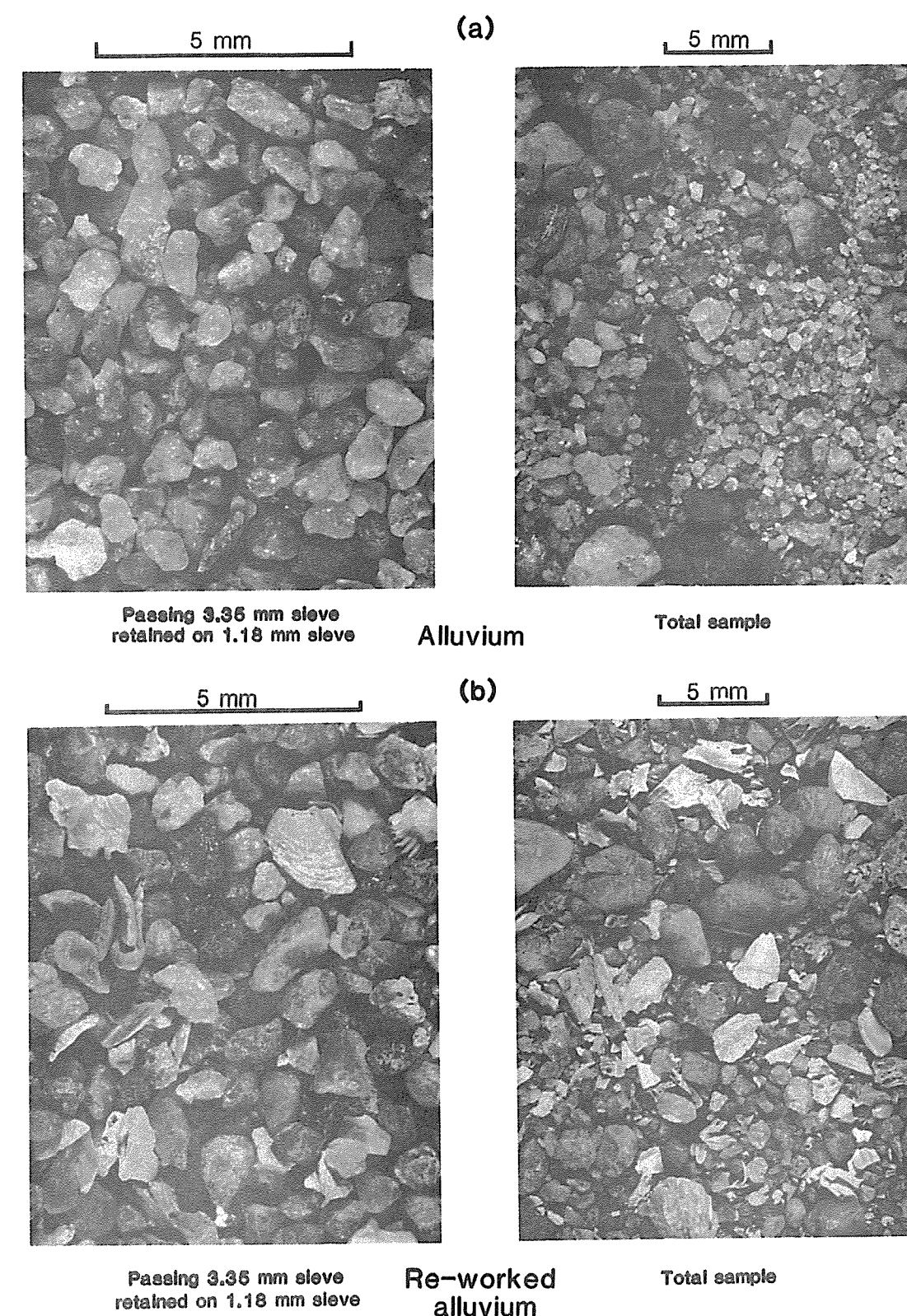


Plate 1 (a) Photograph of sample of alluvial sand and gravel
(b) Photograph of sample from the reworked top of the alluvial sand and gravel (similar to (a) but with shells)

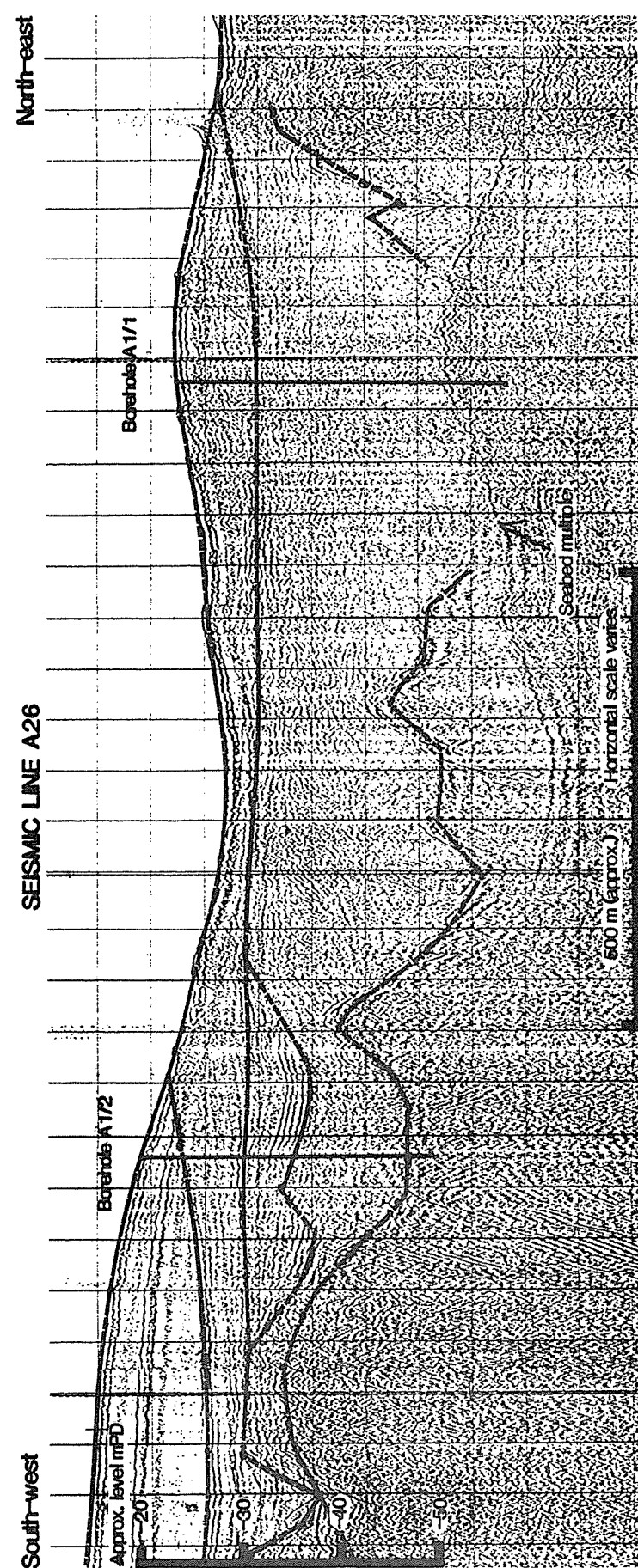


Figure 8 Correlations between boreholes and seismic line A26

Intertidal deposit

Borehole A1/2 (Figure 6) encountered more than 5 metres of a firm brownish grey, slightly organic, sandy clayey silt which grades downwards into a brown alluvial sand. Partings of decomposed organic matter such as leaves are present, as well as small (less than 5mm) gastropod shells, thought to be indicative of an intertidal environment.

Alluvial sand

This is characteristically composed of medium to coarse, clean yellowish brown sand with a variable content of fine, often subrounded gravel. Within this deposit there are occasional, well defined breaks in the sequence, marked by changes in the shade of brown colour or in the average grain size. The sand grains are predominantly quartz, although lithic clasts, especially in the gravel fraction, are present. In general there is a tendency for the sand to become coarser with depth. Individual grains are subangular to subrounded (Plate 1a). The grain size and shape of the quartz clasts suggest that a relatively nearby weathered granite was the main source of the sediment.

The top of the alluvial sand is generally marked by a change in colour from brown to the grey of the overlying marine deposits. However, this change was usually found to be gradual, with the upper part of the alluvial sand generally containing a few scattered shell fragments and some grey coloured fines. These fines and shell fragments are only present in the top few metres of the alluvium, and within this part they rapidly reduce in quantity downwards. It appears that this upper portion of the alluvial sand has been reworked in a beach-type environment (Plate 1b). The average SPT value measured in the alluvial sand is about 50.

Alluvial clay

Inter-bedded, mottled yellow, brown and grey, firm to stiff clays and silts, with subordinate medium dense to dense clayey sands, lie beneath the grey marine deposits in borehole A1/3. This material is typical of the Pleistocene described as Chek Lap Kok Formation by Strange & Shaw (1986).

Grey silty clay

Near to, or possibly at the base of the alluvial sequence, a grey non-shelly silty clay was encountered in several boreholes as shown in Figure 6. These sediments vary considerably, the main characteristic however, being the grey colour and the absence of shells.

Bedrock

Drilling was terminated in a material thought to be weathered bedrock in all boreholes except A1/5.

Correlation between seismic units and boreholes

Figures 5 and 8 show examples of the correlation between the boreholes and the geophysics. The continuity of seismic patterns between traverse lines is good, as can be seen by comparing Figures 5 and 8. The match between the interpreted seismic interfaces and the borehole data is also good. Cross-correlation of the geophysics and the boreholes between intersecting seismic traverses was also consistent. This suggests that, despite the paucity of geological data (about one borehole per square kilometre), the results to date probably give a good indication for the whole area. The main area of uncertainty is the asymmetrical bank in the middle of the present-day tidal channel. So far, it has not been possible to drill the main part of this bank because it is in the centre of the shipping fairway to Kwai Chung Container Terminal. Nevertheless, at the northern end, where the bank has been drilled, it is predominantly sandy (Figure 8), while towards the southern end, the weakness of the seismic reflectors suggests that it becomes finer, perhaps predominantly a mud. Further drilling will be required to determine this.

Figure 8 shows that the intertidal silt sampled in borehole A1/2, corresponds with the seismic unit which is the extension of unit (iv) in Figure 5. Unit (iv) is therefore interpreted to be part of the same intertidal deposit. Similarly, unit (iii) correlates with the marine sand in boreholes A1/4 and A1/2.

The conformability of seismic units (iii) and (iv) suggests that they might be part of one single depositional episode. The borehole data also indicates this because it shows, in A1/2, an intertidal deposit which passes upwards into a marine sand. Such a pattern of sediments is to be expected during a period of rising sea-level.

The predominantly clayey alluvium encountered in borehole A1/3 (Figure 5) is typical of the Chek Lap Kok Formation as described by Strange & Shaw (1986), and it correlates with seismic unit (v).

Unit (vi) is similarly correlated with the alluvial sand and gravel sampled in borehole A1/4, and by extension to Figure 8, the alluvial sand and gravel in borehole A1/1. The horizontally stratified top of unit (vi) appears to correspond to the upper part of the alluvial sand which has been reworked in a beach environment.

The irregular reflector towards the base of Figure 4 is probably relatively hard bedrock.

It must be emphasised that although an individual seismic unit appears to persist laterally, there may be changes in the nature of the sediment. Although the overall correlations between the geophysics and the boreholes is consistent, undrilled areas should only be regarded as 'proven', to a degree of confidence related to the intensity of drilling in that vicinity.

Discussion

The identification of borehole samples as alluvial or marine has been based largely on criteria similar to those discussed by Yim (1983) for the sub-sea sediments which were exposed in the excavations for the High Island Reservoir.

A grey colour and the presence of marine shells has been taken as indicative of a marine depositional environment, and the absence of shells and a brown colour, as indicative of an alluvial origin. The brown

alluvial sand with scattered fragments of marine shells is similar to material found on present-day beaches around Hong Kong and has therefore been identified as such.

The confidence with which the geophysics can be used to apply the borehole information over a wider area, will depend to a great extent on being able to establish a coherent geological model for the deposits. This means developing an understanding of how the sediments were laid down, eroded and so on. There are many aspects to this; the analysis of marine sand banks, by Evans (1988), has already been referred to. Another important aspect of the palaeoenvironment in this area is the pre-Holocene drainage line. It would appear that unit (vi) is made up of granular, river channel deposits, and that unit (v) represents the cohesive alluvium laid down in a flood-plain environment adjacent to the river. The last position of this pre-Holocene river is marked by the depression in the combined (v)/(vi) surface. This depression is now filled with the early Holocene intertidal silt, unit (iv). The upper surface of unit (iv) is concave. This may be due in part, to consolidation of the intertidal silt under the overburden of marine deposits. However, preliminary calculations indicate that the concavity is greater than would be expected from consolidation alone. Therefore, it appears that as the rising Holocene sea penetrated landwards, the pre-Holocene drainage line continued to exist as a gently dished intertidal embayment. Any other such depressions in the alluvial surface are also likely to be infilled with intertidal silt.

When the rising sea-level reached the main alluvial surface, reworking of sand and gravel must have started; initially in a beach-type environment, and then later, as the water deepened and strong tidal flows developed, in a fully marine environment producing the early sand banks discussed by Evans (1988).

The material which makes up the various marine deposits is a combination of reworked alluvium, new sediment from streams, and material derived from coastal erosion during the period of rising sea-level. The type of alluvium most susceptible to reworking is likely to have been the granular alluvium, while the cohesive alluvial surface was probably more resistant. The fact that the pre-Holocene dissected surface (of (v) in Figure 4) only seems to be preserved in cohesive material lends support to this idea. In a study of a potential dam site in Long Harbour in the eastern New Territories, Fanshaw & Watkins (1971) concluded that the coastal sands were not transported more than 90 metres offshore. In the area south of Tsing Yi it would appear that the marine sand bank is predominantly composed of material derived from the underlying alluvium.

The overall steepness of the local topography has dictated the position of the now submerged drainage lines and also the Holocene tidal channels. As a result, areas of high tidal currents in the early Holocene must have tended to coincide with deposits of granular alluvium. It is therefore to be expected that marine sand banks would initially tend to form in areas where the underlying alluvium is granular. The distinctive morphology of the marine sand banks may therefore assist in locating areas where the underlying alluvium is granular.

Kim et al (1983), described a pattern of granular deposits in Asan Bay, South Korea, which is very similar to that discovered south of Tsing Yi. They also concluded that swift tidal currents had produced banks of fine sand by reworking underlying alluvial material. It would appear then, that not only are substantial alluvial sand deposits likely to be found elsewhere in Hong Kong waters, as in fact Berry (1959) suggested, but, given the right conditions, they are likely to exist along much of the south China coast.

Conclusions

The Hong Kong Government's exploration for offshore sources of fill has so far concentrated on locating large deposits of buried alluvial sand and gravel, and in particular, deposits in areas where present-day tidal channels have restricted or prevented the deposition of marine mud.

The two-stage exploration programme commenced with a reconnaissance-level high resolution boomer survey. It was at this stage that it became apparent that in some locations, significant deposits of marine sand also existed, mostly in the form of now covered, moribund banks.

To date, the most promising area targeted for the detailed second stage investigation, is in a present-day tidal channel south of Tsing Yi Island. In this area, the deposits of marine mud are thin or non-existent. Partly covered by mud, is the truncated remains of a low, marine sand bank which appears to be the continuation of the marine sand bank recently dredged for Container Terminal 6. Buried beneath the centre of the channel is a large deposit of clean alluvial sand and gravel, the top portion of which has been reworked in a beach environment. The depth of water in the main target area is between 20 and 30 metres. The bulk of the granular deposits lie between 25 and 55 metres below sea-level.

The deposits found so far are consistent with a geological model which indicates that similar sand bodies are likely to be present elsewhere in Hong Kong and along the southern China Coast.

Acknowledgements

The Author is indebted to Dr C.D.R. Evans of the British Geological Survey, and Mr W.N. Ridley Thomas of Electronic and Geophysical Services, for their helpful guidance and discussion in the interpretation of the seismic records. Dr R. Shaw of the GCO provided a very useful insight into the palaeoenvironmental aspects of the work, and Mr E.B. Choot and Mr P.C.T. Cheung, also of the GCO provided invaluable site records of the drilling and sampling operations.

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WRITTEN CONTRIBUTIONS

Development of the Gammon wire line vibro-corer

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Introduction

In geotechnical terms vibro coring generally refers to a vibratory sampler which penetrates the sea-bed surface, typically 3-6 metres, for the purposes of recovering an "undisturbed" continuous sample. This sampling technique was first used by oceanologists and developed in western Europe by dredging organisations to identify sea-bed deposits and to provide quality control for placed fill.

Current equipment for sampling tends to be housed in a rather cumbersome 'A' frame arrangement which is lowered to the sea-bed. A pneumatic vibrator is then activated from the surface, to drive a 2 to 3 metre sampler. Thereafter the complete 'A' frame is returned to the surface for extraction of the sample.

The known vibro-core models on the market can only operate on a level sea-bed surface and not in boreholes, thus sampling is limited to within a few metres of the sea-bed.

To simplify the operation with resultant advantages of speed, cost and the ability to operate in adverse sea conditions, Gammon have developed a wire-line vibro-corer which enables the apparatus to be run to the sampling depth and recovered on a wireline principle.

The vibro-corer can be used for either:-

- a) sea-bed surface sampling up to 6 metres in length depending on ground conditions; or
- b) subsurface sampling, over a similar length, with the same apparatus passing through the base of borehole casing which has been advanced to the required depth below the sea-bed.

Vibro-coring in Hong Kong

To the end of 1986, with the exception of work offshore of Tsing Yi Island (Maunsell Consultants Asia) and Tolo Harbour (Binnie & Partners), virtually no vibro-coring had been done in Hong Kong.

Occasionally foreign dredging companies have passed through Hong Kong taking a limited number of vibro cores for tendering purposes, but not on a substantial scale.

The first major vibro-coring contract in Hong Kong was awarded to Gammon Construction by the Dutch company Hamdredging, for the quality control of the fill placed in Terminal 6 Kwai Chung. The vibro coring specification for Terminal 6 was developed by Maunsell Consultants Asia and called for some 3500 vibro-cores to be carried out in water depths up to 35 metres but diminishing as the fill was placed.

The specification called for 3 metre samples to be taken on a 30 metre grid for each 3 metre lift of fill deposited. This work was to be done throughout the total reclamation site area.

The ground conditions at Terminal 6 however also necessitated sampling through soft marine clays into the underlying stiff alluvium to determine the levels of a clean interface at the base of the terminal marine excavation. Thereafter sampling was required of the granular fill which was typically medium to coarse sand, often comprising numerous shell fragments and with a fines content in the order of 5 to 15%.

Using their vibro-corer, Gammon have now successfully recovered some 2500 vibro-cores through the deposits at Terminal 6. [It is worth noting that Ham had their own Dutch manufactured vibro-corer in Hong Kong but opted to use the Gammon technique because of its speed, flexibility, low cost and simplicity.]

Merits of Gammon vibro-corer

In comparison to a number of other vibro-corers studied when bidding for Terminal 6 work, the Gammon design offered the following improvements and variations to the more conventional units:

- a) the slim-line nature of the equipment allows work to be carried out, with the same apparatus, either directly on the sea-bed or in the base of a borehole, irrespective of depth.

Particularly in boreholes, continuous 3 to 4.5 wire-line sampling can be carried out through the entire thickness of the sand or clay deposits, at significantly quicker rates of progress than conventional borehole drilling and testing techniques.

- b) by dispensing with the cumbersome 'A' frame, an undulating sea-floor is not a problem. The slim-line barrel functioning perfectly well on irregular sea-bed surfaces. (This was a particular consideration at Terminal 6 where both the dredging and subsequent filling produced uneven surfaces and side slopes that an 'A' frame vibro-corer could not accommodate).

- c) the Gammon system weighs in the order of 500 kilos as against other models which are in the range of 1.5 to 3 tonnes. This enables the Gammon system to be operated without heavy lifting appliances, and for quick sea-bed work, can be used directly over the side of a suitable tugboat. The cost benefits are obvious.

Technical note

It is to be stressed at the outset that whilst the vibro-corer is a sampling technique suitable for most materials likely to be encountered in Hong Kong it is specifically geared to strata identification, classification and chemical testing and quality control.

Experience has shown that strata changes in samples can be readily identified and that samples recovered are truly representative of the strata penetrated. Samples can be used for index testing in the case of cohesive deposits, and in the case of granular deposits vibro-core samples are ideal for sieve and hydrometer analysis. However in loose sands, sand fill and soft cohesive deposits a certain degree of compaction may occur, (not core loss) and the temptation to carry out any triaxial stress testing or density determinations should be treated with extreme caution.

Infilling by marine dumping of a spoil ground
south of Cheung Chau Hong Kong

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Environmental Protection Department

SUMMARY A sounding survey of the marine spoil ground South of Cheung Chau, Hong Kong has revealed an elevated sea-bed profile forming the eastern part of the dumping site. This is thought to be a result of marginal or short dumping of waste from the disposal barges. The effects of this combined with probable sediment drift in a south-westerly direction has created an elevated but ill-defined mound or ridge structure with a north-east to south-west orientation.

Introduction

Three gazetted dumping grounds are currently set aside by Government for the marine disposal of dredged spoil in Hong Kong Territorial Waters. These are located South of Cheung Chau, East of the Ninepin Group and in Mirs Bay (Figure 1). Marine disposal of spoil is controlled and licensed by the Environmental Protection Department under the Dumping at Sea Act 1974 (Overseas Territories) Order 1975.

Of the three spoil grounds, the site South of Cheung Chau is the most heavily utilized. This is mainly due to its proximity to many of the main dredging projects in the Territory, especially those centred around Victoria Harbour, the port development at Kwai Chung and reclamation of parts of the Western New Territories. Materials destined for future disposal at the site may include dredged materials from proposed reclamations and overburden overlying marine sand resources.

The preferential use of the Cheung Chau spoil ground together with the large volume of material disposed in the last two years prompted Government to conduct a detailed sounding survey to determine the sea-bed profile, the pattern of filling and the remaining capacity of the site.

The results of the sounding survey show the eastern half of the spoil ground to be particularly elevated by the formation of a marked topographic high, disposed as an ill-defined ridge or mound centred in the north-eastern quadrant of the spoil ground.

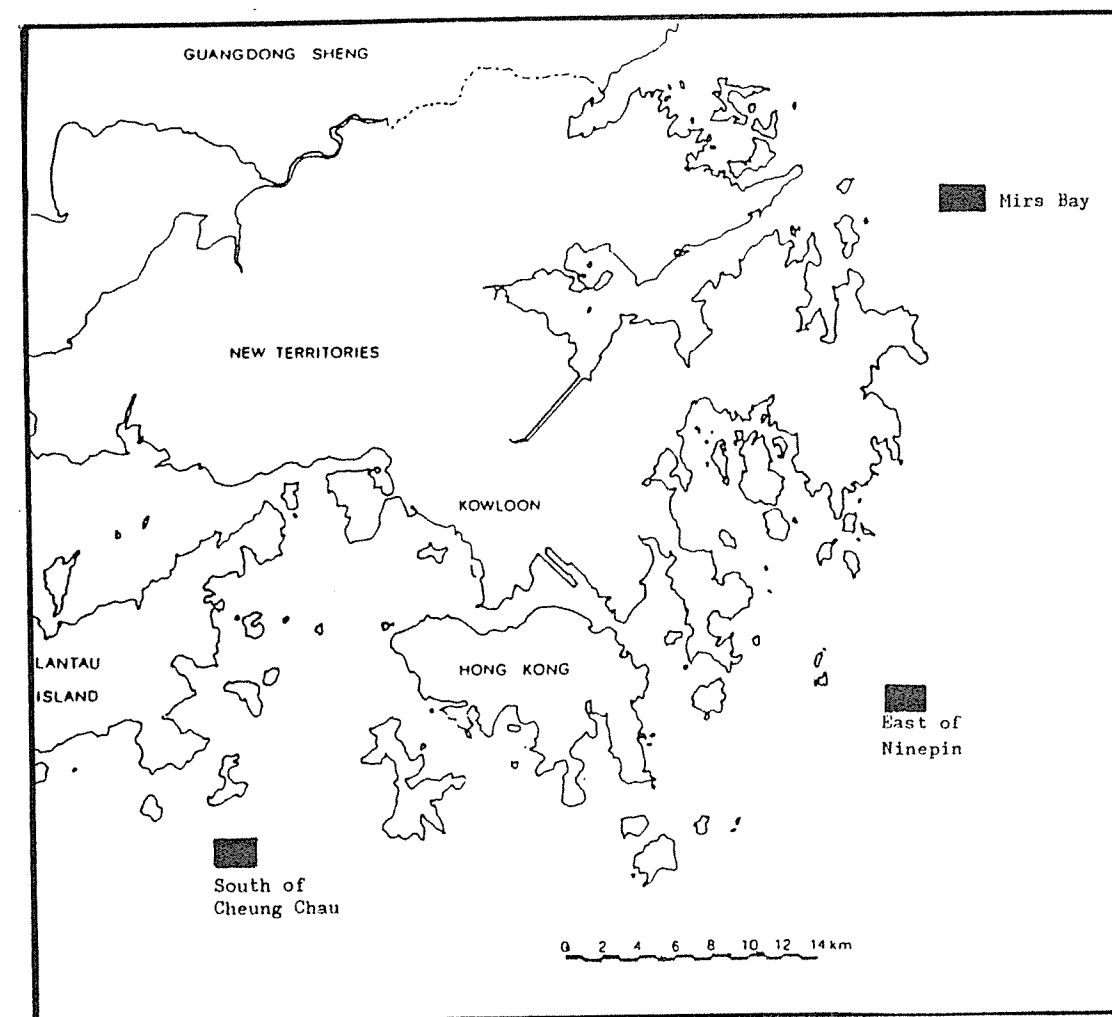


Figure 1 - Location of the Gazetted Spoil Grounds in Hong Kong

Sources and nature of dumped material

The main sources of material dumped at the Cheung Chau Spoil Ground arise from major marine reclamation projects in which soft marine-muds are removed by dredging to improve foundation conditions or to facilitate the placement of sea-walls.

The sediments themselves are typically fine-grained black muds often with organic contamination. Some variation in dumped materials is inevitable as alluvial sands and some weathered rock material may become incorporated into the dredged waste sediment. The method of dredging can also influence the nature of the disposed materials particularly with respect to the amount of fine material recovered or lost during its removal.

Material suitable for reclamation purposes is not usually licensed for marine disposal by the Authority, this is normally directed elsewhere. Materials contaminated with floatable matter are precluded from marine dumping.

Table 1 shows the volume of dredged spoil materials dumped at Cheung Chau Spoil Ground during 1986 and 1987 and also the number of dumping licences issued during this period.

Month	1986		1987	
	No. of Licences Issued	Volume of Spoil Dumped (m ³)	No. of Licences Issued	Volume of Spoil Dumped (m ³)
January	4	36,254	7	2,589,246
February	3	44,000	4	3,282,421
March	5	57,300	7	692,730
April	0	144,870	5	2,394,977
May	8	0	2	97,487
June	4	56,181	2	101,970
July	6	697,367	3	64,130
August	1	940,500	4	48,130
September	5	815,000	4	129,730
October	3	119,500	5	248,630
November	2	744,100	3	314,330
December	5	2,560,000	6	688,503
Total	46	6,215,072	52	10,652,284

Table 1 - Volume of Spoil Dumped at South of Cheung Chau and Number of Licences Issued.

The survey

A sounding survey was conducted by Port Works Division of Civil Engineering Services Department during September 1987 on behalf of the Environmental Protection Department. The survey encompassed the total gazetted area of the spoil ground, some 334 hectares, plus an additional marginal area of 1176 hectares. Survey lines were 75 metres apart with cross check lines at 300 metre centres. A total of 3,700 soundings were taken over a sea-floor area of 15 square kilometres.

The equipment consisted of a radar positioned, automatically recording echo-sounding device with positional accuracy of plus or minus 5 metres.

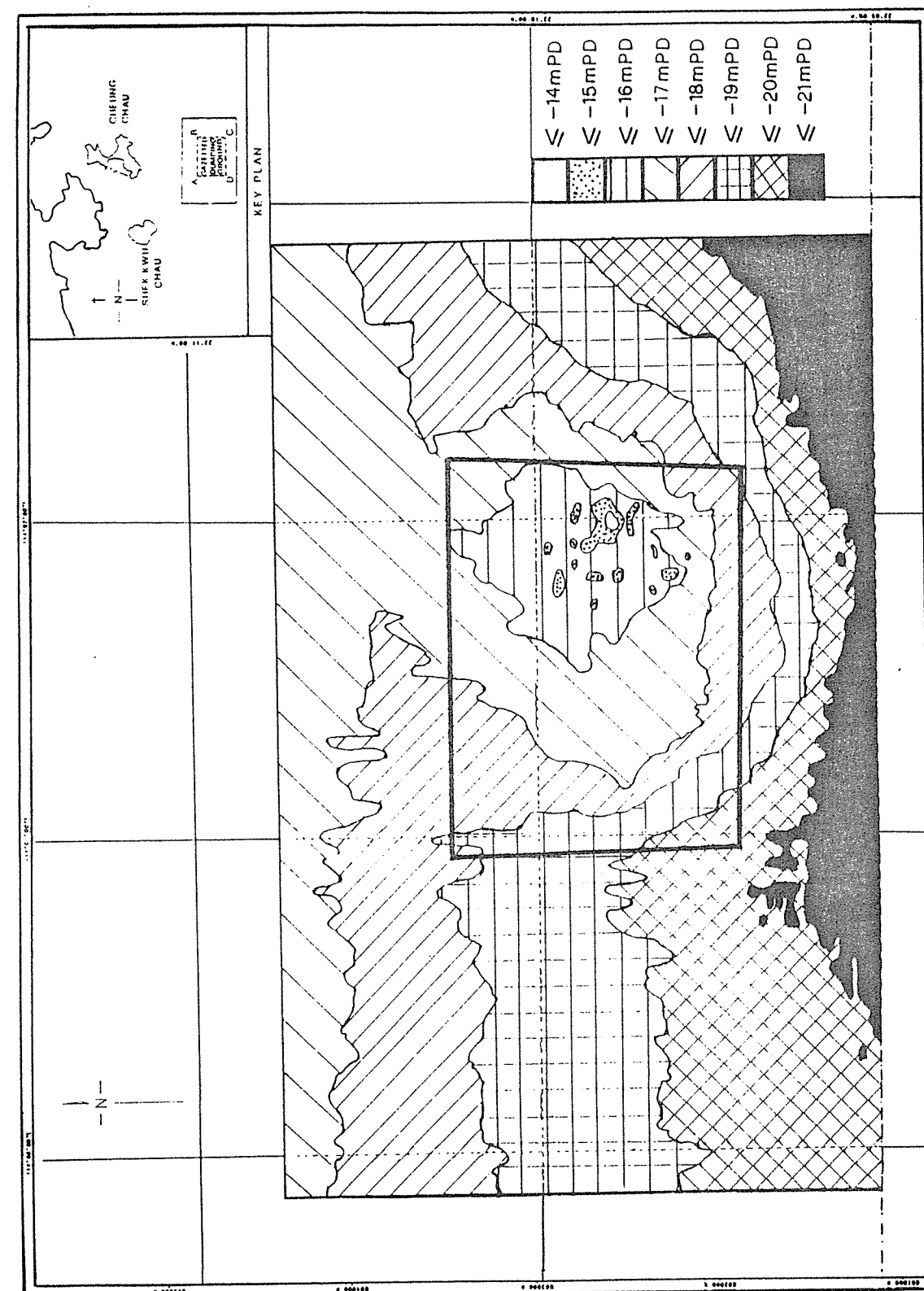


Figure 2 - Contours of the Sea-Bed at the Cheung Chau Spoil Ground and Surrounds

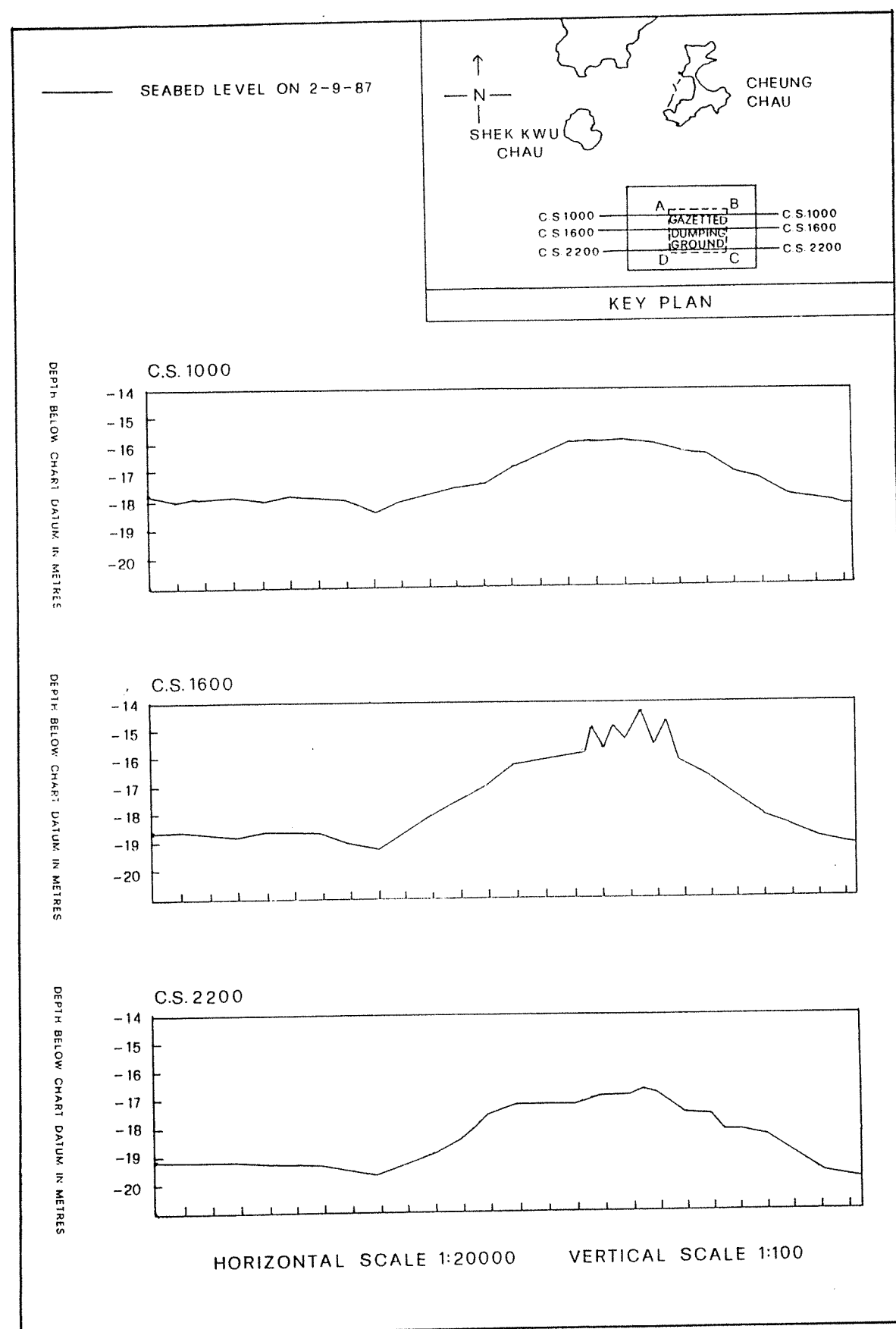


Figure 3: East-West Cross Sections of the Cheung Chau Spoil Ground and Margins

Results

Contours of the sea-bed at the gazetted spoil ground and its surrounds are shown at Figure 2. Contours were drawn at one metre intervals using the data points supplied by Port Works Division.

Three east-west oriented cross sections of the spoil ground and margins are shown at Figure 3.

The contour plan and cross sections show an ill-defined mound or ridge with a long axis oriented in a broadly north-east to south-west direction lying in the northeastern quadrant of the spoil ground. Smaller mounds of dumped material appear to be superimposed on the main structure and reach a maximum elevation of minus 14 mPD.

Interpretation

The area of sea-bed which has been elevated by dumping extends beyond the northeastern boundary of the gazetted area. The orientation of the long axis of the mound may indicate the presence of a tidal or bottom drift of dumped sediments in a south-westerly direction and also suggests that dumping contractors release their loads as soon as, or before, they enter the spoil ground. The sediment dispersion resulting from the directional movement of the dumping vessel and the variable size, shape and density of the disposed material (Figure 4) may also account for the observed filling pattern. Disposal vessels normally approach the dumping ground from the north-east, often releasing materials at the eastern side of the site. The observed sediment distribution is thus not wholly unexpected.

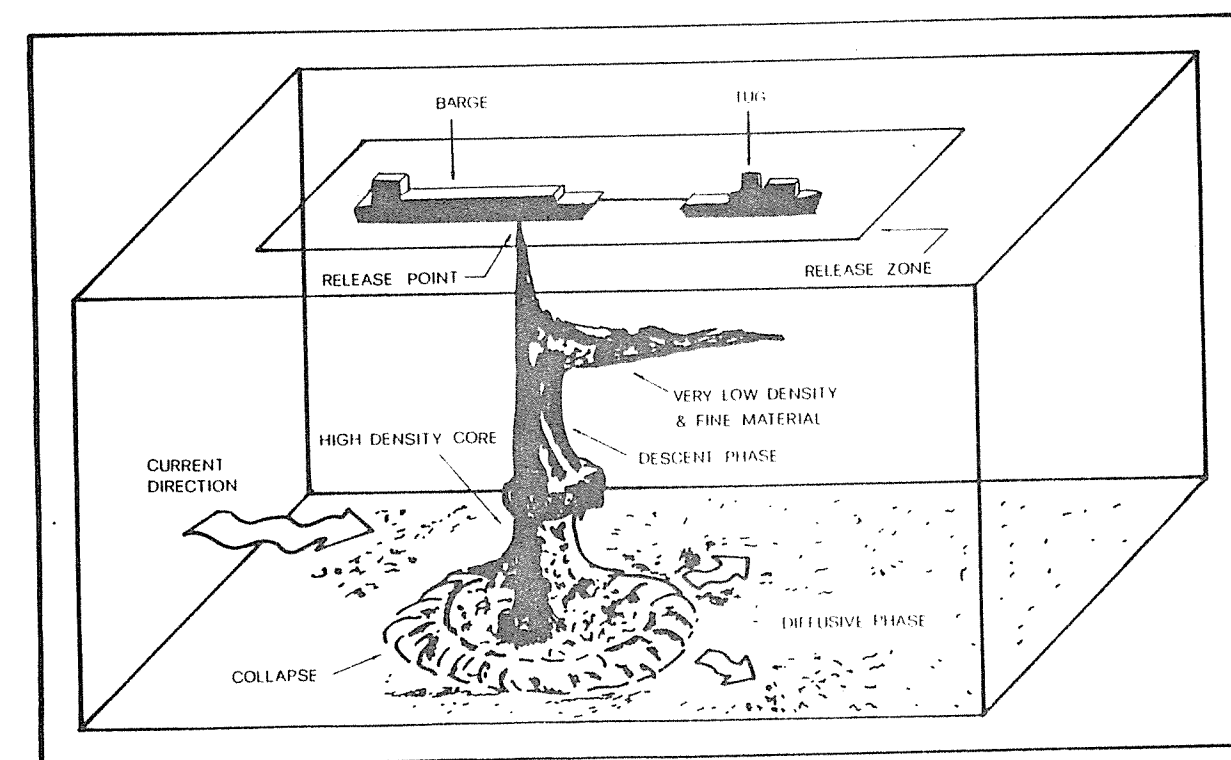


Figure 4 - Transport Process During Open - Water Disposal (After WES, 1986)

Conclusion

- . Filling of the Cheung Chau Spoil Ground has occurred mainly in the eastern part of the gazetted area.
- . Tidal or bottom drift of the dumped material may be occurring in a north-east to south-west direction.
- . The effects of marginal, short or inaccurate dumping combined with the preferred approach route of disposal vessels is causing the eastern part of the spoil ground and environs to fill more rapidly than the remainder. This may have implications not only on navigation but on other uses of the sea-bed.
- . Distinct dumping mounds have formed and appear to be superimposed on a broad, ill-defined mound or ridge formed within the eastern part of the main filling area.
- . Dumping of spoil, particularly the large quantities which may be removed prior to extraction of marine fill, will require careful control.
- . Any extraction of submarine sources of fill from areas adjacent to gazetted dumping grounds could be affected by material which has drifted from or been dumped short of the gazetted spoil ground.

Acknowledgements

This paper is published with the permission of the Director of Environmental Protection. The detailed survey prepared by Chief Engineer Port Works Division, Civil Engineering Services Department is gratefully acknowledged.

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Marine Site Investigation for Sources of Sand in Hong Kong Waters

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Introduction

With the depletion of readily accessible seabed deposits of sand in Hong Kong, it is becoming necessary to consider sources which are located further offshore and those which are overlain by unsuitable materials. To search for these less obvious sources, a properly planned and executed programme of site investigation will have to be conducted. The investigation at Deep Bay for Tin Shui Wai Development (Dutton, 1987) has demonstrated the success of an organised search in uncovering major and previously unknown sources of sand for reclamation. This paper broadly discusses various aspects of site investigation pertaining to the search for marine sources of sand in Hong Kong. Typical difficulties associated with conducting site investigation in a marine environment are described together with a brief discussion of the planning and the application of various techniques of marine site investigation to sand searches. Detailed descriptions of most of the investigation techniques are available in the guidance document on site investigation produced by the Geotechnical Control Office (1987). General reviews of marine site investigation practice and various techniques for sampling recent sediments in Hong Kong have been conducted by Blacker & Seamen (1984) and by Beggs (1983).

Difficulties with marine site investigation

There are various problems that make marine site investigations significantly more difficult than land investigations. A proper appreciation of these problems will greatly facilitate the planning and execution of a marine site investigation project. In many respects, these problems are increased for sand searches because major accessible deposits of sand are often found in exposed offshore areas with deep water and strong currents.

Constantly changing water level is a major problem to overcome for marine site investigation. The heave of a floating craft in response to waves and tidal fluctuations makes an investigation difficult and sometimes dangerous to proceed. Tools and equipment are liable to experience accelerated wear and tear problems in such a hostile environment.

Strong currents can affect a marine investigation in several ways. A casing and drill string, being unsupported through the water column, may become unstable due to the lateral force exerted by the currents. In offshore areas with strong currents, there is often a sandy seabed and this can make it difficult to obtain sufficient anchorage to maintain the required stability of an investigation craft. Strong currents can also

make it awkward to tape the water depth accurately.

Precise positioning of a marine investigation station at a predetermined location is often difficult to achieve. Indirect methods of positioning from shore stations have to be employed and permanent markers cannot be left for possible rechecking of position in case of discrepancy.

Potential interference with other marine activities would at times necessitate lengthy arrangements with the relevant authorities before an investigation can proceed. For safety reasons, various stringent restrictions imposed by the Marine Department of Hong Kong have to be followed. Difficulties may also be experienced when conducting an investigation close to the border of the Peoples Republic of China.

Investigation planning

During the planning stage, a desk study should be conducted of all relevant geological, oceanographical, hydraulic and meteorological information. In particular, information from the following sources should be carefully reviewed.

- (a) Admiralty Charts. A general indication of the water depths, seabed conditions, and potential obstructions such as shipping fairways and underwater utility lines can be obtained from the charts.
- (b) Offshore Geological Maps. An initial impression of the subsurface stratigraphy can be formed from examining the offshore component of the new 1:20,000 scale geological maps of Hong Kong. The offshore component of these maps was primarily based on a compilation of available investigation data (Strange & Shaw, 1986; Geotechnical Control Office, 1986).
- (c) Available Site Investigation Data. A preliminary knowledge of the site conditions can be gained through the review of relevant records of previous site investigations. A comprehensive collection of factual site investigation data of most government projects is available at the Geotechnical Information Unit of the Geotechnical Control Office. Review of the investigation data should take into consideration the possibly wide variations in the standard of investigation between projects.

There is no fixed rule as to the required scope of investigation. Obviously the investigation programme should be kept flexible and adjusted to suit the ground conditions. For budgeting purposes however, Bates (1981) has proposed the following equation as a reasonable guide to the number of boreholes required for evaluating the ground conditions for dredging purposes:

$$N = 3 + \frac{A^{0.5} d^{0.33}}{50} \quad \text{where: } \begin{array}{l} A = \text{area in square metres} \\ d = \text{thickness of deposit to be dredged in metres} \\ N = \text{number of boreholes required} \end{array}$$

To optimise the search effort, these boreholes should be positioned in offshore areas which are geologically likely to have major deposits of sand. Arthurton (1986), Dutton (1987), and Shaw (this volume) have discussed the various possible modes of occurrence of offshore sand in Hong Kong.

Early liaison with the Marine Department and other relevant authorities should be maintained during the planning stage to avoid potential delays to an investigation programme.

Investigation techniques

Geophysical survey

The techniques of marine geophysical survey have been discussed in detail by Ridley-Thomas et al (this volume) and Ridley-Thomas (1982). The survey has the advantage of being able to rapidly acquire a continuous indicative record of the subsurface stratigraphy across an area being surveyed. It is important to note that geophysical survey is only an indirect method of investigation and borehole controls are mandatory.

Echo sounding is a form of geophysical survey carried out to determine the seabed levels. Countours of seabed levels can reveal seabed topographical features such as 'sand' bank and tidal channel indicative of the possible existence of seabed sand in the vicinity.

A side-scan sonar acquires an acoustic image of the seabed by radiating acoustic signals perpendicular to the travel direction of the survey vessel. The records obtained can reveal the presence of seabed features such as sand waves and possible underwater obstructions such as a rock outcrop or a submarine utility line.

Subbottom seismic profiling is carried out to obtain an indicative record of the surfaces between different subsurface materials. Both the shapes of the surfaces and the characteristics of response known as seismic signatures can be examined to locate possible existence of sand bodies. The survey however cannot pick up the interface between materials of different properties but similar acoustic impedances.

Surface seabed sampling

Various forms of seabed sampling techniques can be employed in offshore areas where shallow seabed sands are expected. These techniques have the advantage of being quick, relatively inexpensive, and are significantly less susceptible to operational constraints such as water depth and strong currents applicable to conventional methods of investigation. Many seabed samplers are lightweight in construction and can be operated from a small craft.

There are three main types of seabed sampler: grab sampler, gravity sampler, and vibrocorer. Within these three main types, many variations are possible.

The grab sampler has a very shallow penetration depth of only about 0.1 metre. The two common types of grab sampler, the Shipek and Van Veen grabs, differ in operating mechanism and can obtain about 0.003 and 0.0075 cubic metre of seabed materials respectively. They are ideal for sampling surface sediments and have been used in Hong Kong for such purposes as providing the control for the interpretation of side-scan sonar records and for pollution studies. Larger size grabs can be used, and in Hong Kong, contractors often mobilise clamshell grabs capable of providing several cubic metres of sample to prospect for surficial sand for construction purposes.

A gravity corer can be used to provide samples of seabed materials up to a depth of about 6 metres. The main components of a gravity corer are a sampling barrel of various possible combinations of diameters and lengths, and a streamlined weight which is attached to the top end of the sampling barrel. The corer is allowed to drop through the water column and penetrate into the seabed by its own weight. Common barrel lengths range from 1 to 6 metres and common core diameters from 50 to about 150 mm. The steel barrel is usually lined with a PVC liner to retain the sample. Sample retention is aided by the incorporation of a butterfly valve or an appropriate core catcher at the base of the sampling barrel, or alternatively, a piston mechanism can be incorporated.

A vibrocorer can provide seabed samples to a depth of about 6 metres. The sampling tube is generally similar in construction to that of a gravity corer except that the penetration of the sampling barrel into the seabed is achieved by the impact of a vibratory drive attached to the top of the sampler. Because the impact frequency and force can be positively controlled, near 'undisturbed' samples can be obtained and penetration into a range of seabed materials is possible. In dense materials, jetting arrangements are sometimes incorporated to assist penetration. Most vibrocorers are usually fitted on to a purpose built seabed frame and remotely operated, although recently a contractor in Hong Kong has successfully developed a vibrocorer which can operate within a casing as well (Smyth, this volume). The potential loss of silts and fine sands through induced liquefaction is a common problem with vibrocorers.

Subsurface investigation

The choice of an appropriate overwater support for the investigation equipment is an important consideration for subsurface investigation. The use of a jackup platform would be ideal as a stable base for investigation except that the platforms currently available in Hong Kong are restricted to a maximum operating depth of only some 12 to 15 metres. Because most investigations for offshore sand sources are in deeper waters, floating craft are commonly employed. Normal investigation craft in Hong Kong vary from about 200 to 500 tonnes in displacement. In the more exposed offshore areas, craft of a substantially higher displacement should be used to minimise the problem of heave.

Where an investigation station is located a few kilometres away from shore, electronic means of positioning should be used, and a rough check of the position of each investigation station should be carried out with a sextant sighting. At the commencement of investigation, an accurate measurement of the seabed level should be made inside the casing immediately prior to its complete lowering onto the seabed.

The site investigation technique that is preferred for sand search is cable tool percussion boring. This technique of investigation utilises the percussive action of a shell/bailer to advance a borehole. The main advantage of percussion boring over the more commonly used method of rotary drilling is that potential disturbance to granular materials is minimised by not flushing the borehole with drill water. Materials bailed out from the boreholes can, if properly handled, serve as large backup samples for the investigation, and this is important when sampling granular materials where poor sample recoveries are to be expected.

Whenever possible, continuous sampling should be conducted for the initial boreholes of an investigation programme. This permits the uncovering of minor stratigraphic details such as cementation which could affect subsequent dredging operations and which might be missed by sampling at discrete intervals. Various sampling methods that can be used and the expected sample qualities have been described in detail by Beggs (1984). The potential use of the airlifting technique to obtain bulk samples of subsurface granular materials deserves mentioning. Dutton (1987) described the successful use of an airlifting arrangement at Deep Bay to qualitatively assess the degree of susceptibility of subsurface granular materials to flow if extracted by hydraulic methods of dredging.

Whenever granular materials are encountered, the standard penetration test (SPT) should be conducted as it is the most widely correlated test to determine the in-situ properties of granular materials. In soft cohesive materials, vane shear testing (undisturbed and remoulded) is an important field test. An accurate definition of stratigraphy can be obtained by conducting cone penetration testing. Cone penetration testing however requires a stable platform, and unless the problem of limited operating depth of available jackup platforms is overcome with possible alternative arrangements such as the use of heave compensating devices or lightweight seabed remotely operated units, cone penetration testing is likely to remain limited in application as a tool for sand search in Hong Kong.

Laboratory testing

Laboratory testing is an integral part of a site investigation programme. Its primary purpose is to objectively determine the compositions and characteristics of materials sampled from site. The report by the Permanent International Association of Navigational Congress (PIANC, 1984) provides general guidance on the recommended scope and types of testing on soils for dredging purposes (Groothuizen, this volume).

For granular materials, as it is virtually impossible to obtain truly 'undisturbed' samples with routine methods of sampling, the emphasis of a laboratory testing programme should be on index testing rather than on undisturbed testing. Attempts should be made to qualitatively describe the grain shape (angular, rounded, elongated, etc), grain texture (smooth or rough), and possible mineralogical composition and hardness of grain (quartz, shelly, lithic, etc) as all these properties have obvious effects on the wear and tear rates of dredging equipment. Where the fines content exceeds some 15 percent, Atterberg limits of the fines should be determined. Internal angles of friction from appropriate strength testing are useful for assessing the stability of dredged slopes and the behaviour of the materials during a dredging operation. Compaction tests are carried

out to determine the expected range of densities of the materials when used in construction.

In cases where the target sand deposits are overlain by unsuitable cohesive materials, it is equally important to test the cohesive materials as their properties will have definite impact on the production rates of a dredging operation. Besides a range of index testing, some strength testing both on undisturbed and remoulded samples should be conducted. Simple strength tests with a torvane or a hand penetrometer should routinely be carried out as they provide useful indications of the approximate strengths and may highlight potential disturbance experienced by the test samples. In some cases, clay mineralogy should be determined as the result can be used to indicate the possibility of clay balls formation which could severely affect the operation of hydraulic methods of dredging. It should be noted that the proper differentiation between silts and clays should be based on Atterberg limits rather than on hydrometer analysis.

Representative samples of each of the major types of materials on site should also be kept in their natural states in properly labelled airtight containers to facilitate the subsequent examination by dredging contractors.

Acknowledgements

This paper has been published with the permission of the Director of Civil Engineering Services of the Hong Kong Government. The technical review by Mr P. G. D. Whiteside of the Geotechnical Control Office is gratefully acknowledged.

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Resource and Reserve Definition for Offshore Materials in Hong Kong

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Introduction

Modern methods of searching for economic deposits of offshore materials have considerably improved the reliability with which these bodies can be located and evaluated. Systematic exploration is a prerequisite to any modern extraction operation, and an agreed terminology must be adopted to accurately convey the level of confidence achieved in defining resources and reserves of offshore materials.

Recent exploration for offshore fill deposits in Hong Kong by the Geotechnical Control Office, described by Shaw (this volume) and Whiteside (this volume), has highlighted the need to refer to any bodies of material so found in terms that are formally defined and, if possible, generally agreed and understood. In order to do this it is first necessary to undertake a thorough assessment of the existing systems for the descriptions of resources or reserves of sands, aggregates or other bulk minerals. Then it is necessary either to adopt or adapt an existing system, or to suggest a new system; adapting an existing system is preferable.

Exploration and evaluation

There are two distinct phases in the search for minerals, which apply equally to the search for offshore materials as sources of fill or aggregate. These are exploration and evaluation; exploration is the study of large areas to understand their geology, and evaluation is the testing of individual target bodies to prove their worth.

Having located and examined a bulk mineral body, a clear distinction must be made between those bodies, or parts of bodies, that are workable and those that are not. For the description of coal deposits, long practice has led to the adoption of certain borehole spacings in order to categorize the reserves under study. Economic factors are introduced into the evaluation of the reserve quantities of whatever category by incorporating a recovery factor, an overall depth limit of mining and, in opencast mining, a limit in the ratio of seam thickness to thickness of overburden. These factors are not used in the setting of the levels of confidence used for the categorization of the deposits.

In the search for offshore fill in Hong Kong the exploration phase consists of a planned grid of reconnaissance seismic survey lines coupled with a broad appreciation of the stratigraphy and genesis of offshore superficial deposits (Shaw, this volume). The evaluation of likely prospects is done both by closely spaced seismic survey lines and by continuously sampled boreholes (Whiteside, this volume) and vibrocores. Economic factors are introduced by considering depth of dredging and thickness of overburden.

Resource and Reserve Definition

A number of definitions of resources and reserves have been published, and the following are taken from Bates & Jackson (1980):

Speculative resources. Undiscovered mineral resources that may occur either in known types of deposit in a favourable geologic setting where no discoveries have yet been made, or in as yet unknown types of deposit that remain to be recognized (Brobst & Pratt, 1974, p.2).

Hypothetical resources. Undiscovered mineral resources that we may still reasonably expect to find in known mining districts (Brobst & Pratt, 1973, p.4).

Identified subeconomic resources. Mineral resources that are not reserves, but that may become reserves as a result of changes in economic and legal conditions (Pratt & Brobst, 1974, p.2). In this paper these are referred to as conditional reserves.

Identified resources. Specific bodies of mineral-bearing rock whose existence and location are known (Brobst & Pratt, 1973, p.3). They may or may not be evaluated as to extent and grade. Identified resources include reserves and identified subeconomic resources.

Resources. Reserves plus all other mineral deposits that may eventually become available; either known deposits that are not economically or technologically recoverable at present, or unknown deposits, rich or lean, that may be inferred to exist but have not yet been discovered (Brobst & Pratt, 1973, p.2).

Reserves. Identified resources of mineral- or fuel-bearing rock from which the mineral or fuel can be extracted profitably with existing technology and under present economic conditions (Brobst & Pratt, 1973, p.2).

Reserve classification

A reserve is that part of a resource that can be extracted profitably with existing technology under present economic conditions or, in the case of conditional reserves, with marginally improved technology, more favourable economic conditions or both. If conditions change part of a resource may be recategorized as a reserve and vice-versa. For example, improvement of dredging capabilities may allow a greater depth of extraction and thus bring more material within the scope of operations.

The U. S. Geological Survey (1976) defined reserve classes for coal deposits based on borehole spacings, as shown below:

Measured reserves	0.8 km spacing for boreholes
Indicated reserves	2.4 km spacing for boreholes
Inferred reserves	9.6 km spacing for boreholes
Identified reserves = Measured reserves + Indicated reserves	

Macdonald (1983) presented many classes of reserves. These include proved, measured, developed, indicated, partly developed and inferred. Of these, the most useful and widely accepted classes seem to be similar in concept to those of the U. S. Geological Survey (1976). The category of conditional reserves which Macdonald quotes from the U. S. Geological Survey is synonymous with the term conditional resources, also a synonym for identified subeconomic resources. It is immaterial whether the term reserve or resource is used in the conditional context, as long as it is clear that these deposits are known in grade, volume and location, although theoretically

reserves should not be referred to as subeconomic. In this paper such deposits are called conditional reserves because the amount of information obtained regarding their quality and quantity is the same as for the recoverable reserves with which they are associated. These concepts are summarized in Table 1 (After Jensen & Bateman, 1981).

Assuming that technological and economic conditions remain the same, reserve categories will differ from each other only in terms of the information known about them. It is reasonable, therefore, to expect to be able to apply the terms measured, indicated, inferred and identified reserves to deposits of either fill or aggregate, with the provision that the level of information required for defining the boundaries between reserve classes will differ from one type of bulk mineral to the next.

Recommendations

The delineation of a reserve from a resource will require information such that the conditions of the definition of the term reserve can be seen to be applicable. Therefore, the grade of the material, the volume of the deposit and its location must be known, together with broad indications as to its economic extractability. The interrelation of these factors will vary according to the value of the material extracted and the end use. In terms of offshore materials in Hong Kong, small quantities of high grade aggregate could be profitably extracted from deep, distant reserves of small volume. This does not apply to sources of fill, which would normally be larger and more accessible.

Until the three factors of grade, volume and location are satisfied a deposit should not be referred to as a reserve. For example, in the GCO Fill Study this clearly applies to the possibly granular materials recognized as cross-bedded sediments from geophysical traverses across the area south of Stanley Area (Target A2). Since no drilling has been carried out, no confirmation of the lithology or grade of the deposits can be made and they should not be referred to as a reserve but as a resource. However, in order to differentiate them from other resources they could be referred to as discovered or potential resources. By definition, potential resources are deposits that have been identified by some means, but that have not been characterized as to extent or grade.

The determination of the category of reserve to which the deposits are referred is a much more complex problem. In Target A1 (Tsing Yi), the information obtained in the fill study is approaching the level such that the deposits in question might be classified as reserves. There is good information about their location and a broad indication of their grades and volumes. However, it may not be critical whether they are regarded as identified reserves or inferred reserves. What is more important is whether any of the deposits should be referred to as conditional reserves. This will depend on such factors as the depth from which the materials may be economically dredged and the thickness of overburden that can economically be removed. Probably all deposits found at a depth greater than say -45 mPD should be regarded as conditional reserves, and quantities of material quoted should be clearly distinguished from the recoverable reserves. The depth for the cut-off used is dependant on technological and economic conditions, but should always be quoted in reserve calculations.

The establishment of exploration and evaluation practices is not the intention of this paper but it should be noted that the borehole spacings used for determination of coal reserve hierarchies are probably much too wide for

use on alluvial or marine sand deposits. Coal deposits are much more laterally uniform and predictable in their occurrence, when compared to the sand bodies known to occur in Hong Kong. Although it may as yet be premature to define the differences in exploration levels between reserve categories, it is essential to apply a firm basic terminology in order to accurately describe the deposits of fill and aggregate offshore.

From the definitions presented in this paper it is suggested that the offshore sources of fill can be broadly classed as resources, and more specifically as hypothetical resources. A new class of resource is also presented, referred to as discovered or potential resources, to allow better definition of resources at a stage in the exploration process that is intermediate between discovery and evaluation (Table 1).

In the UADO Fill Study the hypothetical resources have first been recognized as potential resources, such as the deposits south of Stanley. Recoverable reserves with associated conditional reserves have been defined both south of Tsing Yi and north of Lantau. In the future it may be useful to define classes of recoverable and conditional reserves of fill or aggregate based on formally defined standards of site investigation.

Acknowledgments

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Table 1 Resource and Reserve Classification (After Jensen & Bateman, 1981)

IDENTIFIED RESOURCES				UNDISCOVERED RESOURCES	
EVALUATED RESOURCES		DISCOVERED RESOURCES			
Deposits that have been evaluated		Deposits that have been recognized as potential resources		Similar deposits have been extracted in the district	Appropriate geological setting occurs in the district
Recoverable reserves		Potential resources	Hypothetical resources	Speculative resources	
Identified					
Measured	Indicated				Inferred
Conditional reserves					
Identified					
Measured	Indicated				Inferred
EVALUATION		EXPLORATION			
<<<<< INCREASE		Degree of certainty of existence		DECREASE >>>>>	

WRITTEN
DISCUSSION

WRITTEN DISCUSSION

DEPOSITION AND EROSION

Mr J.H.A.Thornely (China Light & Power Company Ltd), referred to the paper by Dr Evans (presented by Dr Addison), and asked if he was implying that in the tidal channel running between Urmston Road, Ma Wan and Green Island (Figure 2 in the paper by Evans) there was unlikely to be significant marine deposition. The reason for the question, stated Mr Thornely, was that China Light & Power had found that in their dredged channel, north of Lantau, for the approaches to Castle Peak Power Station, there is ongoing marine deposition of the order of 0.5 to 1.0 metre per year. It would be interesting to have a comment on the likely rate of marine deposition in this situation, and on whether the depositions observed are a direct consequence of the dredging of the approach channel.

Dr R.Addison (Geotechnical Control Office), answering on behalf of Dr Evans, stated that sedimentation rates of 0.5 to 1.0 metre per year certainly did seem to be exceptionally high. Chalmers (1984) estimated that present sedimentation rates of about 40mm per year might be expected from the deposition of the suspended load in seawater, but he concluded that wave action and current action removed excess sediment and maintained the sea-bed in a dynamic equilibrium.

If however, equilibrium is disturbed by dredging, then re-accumulation in the dredged channel might occur by slumping of channel walls or formation of areas of slack current where mud would preferentially build up. In addition, dredging itself would increase the suspended load of mud in the passing current and this load would be redeposited downstream.

It is of note that Wong et al (1987) quoted sedimentation rates in Deep Bay of from 8 mm per year, calculated from historical navigation charts, to 16.6 mm per year, measured by Pb₂₁₀ dating of gravity core samples.

Strange & Shaw (1986) quoted evidence of local areas of significant erosion of marine mud; presumably other areas could accumulate mud in a similar local response to changing currents.

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RESOURCES

Mr J.H.A.Thornely (China Light & Power Company Ltd), in referring to the paper by Mr Whiteside, stated that over the next 20 years Hong Kong's urban development is likely to require of the order of 100 million cubic metres of reclamation. With this in mind, China Light & Power were undertaking a full-scale demonstration of the use of PFA as a reclamation material. He then asked to what extent have suitable marine sources of fill

of the required quantity been located to date. He was also interested to know to what extent other sources of fill were envisaged.

Mr P.G.D. Whiteside (Geotechnical Control Office), acknowledged that it was quite probable that over the next twenty years, volumes considerably in excess of 100 million cubic metres might be required for reclamation. He pointed out that in the short time that the Hong Kong Government's survey had been running it had already found indications of at least a 100 million cubic metres of granular material; and that was just in the main part of the Territory so far explored. The geological model which was used to explore for these deposits is likely to be applicable to the remainder of the Territory. In fact, given the quartz rich nature of most of the hinterland of the Territory it would not be surprising if there were large deposits of granular material all over the Territory.

For many years the surface cover of Holocene marine mud has led most interested parties to feel that the subsea deposits were not going to be useful as a source of reclamation material. This notion is now, hopefully, well and truly dispelled.

The use as fill, of other materials such as PFA, is clearly a possibility, despite the large resources of granular material which now appear to be available; although it may be that PFA's potential as a specialist lightweight fill for engineering purposes is more likely to be realised than its use for general reclamation purposes.

DREDGING

Mr M.L. Chalmers, (Scott Wilson Kirkpatrick & Partners), noted that Mr Groothuizen, in his paper on "Dredging Methods and Materials for Reclamation", had stressed the importance of productivity and cycle time in determining unit costs for dredging. Mr. Chalmers asked whether productivity would be expected to drop significantly with a consequent rise in dredging costs, if sand were to be dredged by a trailing suction hopper dredger at say 40m depth compared with 30m, assuming all other factors remained the same.

In reply, Mr. Groothuizen (Van Oord International BV) stated that although dredging costs would of course be greater at 40m, as long as the dredger had been designed to dredge to 40m, he would not expect a very significant increase in overall dredging costs.

Mr Chalmers also observed that a large number of trailing suction hopper dredgers are claimed to be able to dredge to depths of 30m, but relatively few are able to dredge deeper in trailing mode. A recent survey indicated that there were less than 20 such dredgers in the world capable of dredging to 32m or more.

One method of dredging deeper is to fit an underwater dredge pump on an extended trailing arm. A few dredgers already have this, and others could be modified if sufficient time was available and the scale and nature of a project justified the expense. In some cases it may be possible to dredge material from a depth slightly greater than the published figure for a given dredger by careful planning of the dredging operations to make use of the fact that the maximum dredging depth for a trailer increases as the hopper is filled and the draught increases. The dredging capability can also be extended by dredging the deepest areas at low tide.

The number of cutter suction dredgers for deep dredging is even more restricted than for trailers. Most large modern cutter suction dredgers suitable for civil engineering projects can only dredge to a maximum of 25 or 30m, and based on a review of published data, none was able to dredge beyond 35m.

On more general aspects of utilising marine sources of sand, Mr Chalmers added that large amounts of effort are currently being expended on marine site investigations to identify, quantify and assess sand sources. As seen in seismic traces (eg Figure 5 in the paper by Whiteside), major dredging operations leave behind them a very confused seabed which is difficult to interpret subsequently. Under these circumstances, Mr. Chalmers suggested that as a condition of granting a license to extract marine sand in a particular area, the licensee could be required to deposit with the Geotechnical Control Office basic information relating to the extent of the dredging works (e.g. area worked, maximum depth, method used, approximate quantities etc). This would assist in assessing the extent of the remaining sand resources for future projects. Submission of before-and-after surveys could also be considered.

RECLAMATIONS

Mr H.R.A. Chamberlain stated that he would like to endorse the suggestion made by Mr C.M. Guilford; namely that marine mud should in future, be considered for use in reclamation, thereby removing the necessity to find dumping grounds for it. This might be done by including in future reclamation schemes, areas where settlement would not be a problem (eg sports grounds, cultivation etc) and pumping the unwanted mud into this area. Such an area would have to be bunded and free of drainage and other pipeworks.

On the subject of specifications for reclamation fill, Mr Chalmers (Scott Wilson Kirkpatrick & Partners), suggested that specifications for reclamation fill should preferably be aimed at performance under various end-user conditions, rather than at particular materials. Although this has been the case in the past, where fills of completely decomposed rock have been used, there is a tendency to create special requirements when different fill material, such as marine sand or PFA, is introduced. This approach tends to restrict development unnecessarily. Probably the two most important end-user requirements, after satisfying the requirement for a stable, durable fill with adequate bearing capacity and strength, are the amount of future consolidation within a given project time scale, and where appropriate, the ease of piling. These requirements can be achieved by a variety of materials. Secondary factors such as resistance to corrosion and environmental effects, often related to placement, can also be included in a specification without being restrictive to certain materials. In particular it has been shown recently that if drainage path lengths are kept small, either by the use of band drains or by layering the fill material, then poorer quality materials can be used for reclamations.

This can be related particularly to fines contents. At Kai Tak Airport, maximum fines contents of between 15 and 25% were specified for different parts of works. More recently at Tuen Mun New Town and elsewhere, the limit has been increased to 30%. Current research in Singapore is aimed at using marine mud as reclamation fill sandwiched between thin drainage layers of sand. At Tianjin, the port expansion is being built on land reclaimed with material dredged from the river, mainly silty clay, improved with vertical drains and vacuum treatment.

As dredging and placing methods tend to wash out fines, often intentionally to reduce fines content to within specified limits, then care needs to be taken to ensure that these do not settle within the reclamation to form soft deposits which will not readily consolidate and which may

block drainage paths and cause instability. Conversely, if the fines are washed out outside the reclamation area, they may cause environmental or siltation problems to adjacent areas.

AGGREGATES

Mr J.H.A.Thornely (China Light & Power Company Ltd), in reference to the paper by Mr Carbray, questioned,

1. In what proportions are the fine and coarse marine and alluvial sands shown in Figures 2 and 3, generally used in concrete in Hong Kong ?
2. What benefits do these imported sands impart to concretes used in Hong Kong, other than the improved wear resistance as is illustrated in Table 7 ?
3. To what extent does PFA incorporated into pavement quality concrete contribute directly to wear resistance, in addition to its improvement of concrete durability, strength, workability and surface texture ?

Mr Carbray, (Geotechnical Control Office) in reply to the questions 1 to 3, stated,

1. There are two types of sand brought into the Territory at present. Namely, Marine Sands (PRC) and River Sands (PRC). The quantities imported during the past year were 87,000 and 1.3 million tonnes respectively. The Marine Sands (PRC), by virtue of their fineness, are unsuitable for use in concrete and are used in mortars, renders etc. The River Sands (PRC) are generally used in finishes, screeds, renders, grouts etc. Around 27% of river sand is used as a fine aggregate in structural concrete. Concrete containing river sand therefore accounts for only 7% of the total consumption of concrete in the Territory. Coarse alluvial and marine sands are not used in Hong Kong at present.
2. The substitution of crushed rock fines by river sands would result in an increase in the workability of the mix. Therefore, for equivalent workabilities, the water requirement of a concrete mix containing river sand would be lowered, and thereby a corresponding reduction in cement content could be achieved.
3. I would envisage that the incorporation of PFA in pavement quality concrete would result in an improvement to the wear resistance of the surface texture by virtue of the improved long term gain in strength which is generally expected of PFA/OPC mixes. However, wear resistance should not be confused with skid resistance for which there would be no improvement.

ENVIRONMENTAL ASPECTS

Mr H.R.A.Chamberlain has said that with regard to the possibility of dredging sand from close inshore, this may not necessarily have an adverse effect on beaches provided it is not taken more than a couple of metres below the sea-bed. An example of this was at Sha Lo Wan where sand was removed for use in filter beds. After completion of the works the local villagers requested that protective works be constructed because they feared that the beach would be eroded. However, surveys indicated that the

hole in the sea-bed from where the sand had been taken, had been filled in by wave action without measurable alteration to the beach profile. Rather than build unnecessary sea defences, a pier was built to satisfy the villagers and provide a useful facility.

It has been pointed out that the dredging process often puts finer sea-bed material into suspension thereby possibly causing pollution in the surrounding waters. I suggest that this could be over-emphasised, since typhoon generated waves produce a similar effect several times a year. Only in very sheltered waters, with a polluted sea-bed, close to a sensitive area such as an oyster bed, is there likely to be a problem.

Mr J.H.A.Thornely (China Light & Power), in referring to the paper by Mr Holmes, said that Mr Holmes described the localised settlement of fine sediment put into suspension during dredging operations and the rapid recovery of the benthos after completion of the dredging, as evidenced by two projects. Could Mr Holmes comment on the likely effect of the imminent large scale dredging and transport activity, on the water quality and mariculture in the Deep Bay area ?

In reply, Mr P. Holmes (Environmental Protection Department) stated that the most immediate impact of the dredging in Deep Bay will be the loss of a small area of oyster beds which will be removed in dredging an access channel. The main dredging for fill material will of course release a considerable volume of silt into the water. The water quality is already poor, and the oysters are forced to tolerate a silty environment under normal circumstances. They would probably fatten quicker in a less silty environment. However, model tests have been carried out to determine how far the silt from the dredging operation might spread, and it has been predicted that dredging in outer Deep Bay will not cause damaging silt deposition on the commercial oyster beds.

LIST OF REGISTRANTS FOR THE SEMINAR ' MARINE SOURCES OF SAND'
HELD IN THE HONG KONG ARTS CENTRE, DECEMBER 4th 1987

Adams, Mr M.G., Mott Hay & Anderson
Addison, Dr R., Geotechnical Control Office
Arul-Kumaran, Mr A.R., Civil Engineering Office
Atherton, Mr M.J., Hong Kong Polytechnic
Au, Mr C.S.V., Scott Wilson Kirkpatrick & Partners
Au Yong, Mr C.K., Territory Development Department
Bouwman, Mr J.H.G., Volker Stevin Dredging BV
Boyd, Mr J., Maunsell Consultants Asia
Brand, Dr E.W., Geotechnical Control Office
Bunn, Mr J.G., Territory Development Department
Burnett, Dr A.D., Geotechnical Control Office
Carbray, Mr T., Geotechnical Control Office
Chalmers, Mr M.L., Scott Wilson Kirkpatrick & Partners
Chamberlain, Mr H.R.A.
Chan, Mr T.P.A., Scott Wilson Kirkpatrick & Partners
Chan, Mr R.K.S., Geotechnical Control Office
Chan, Mr M.C., Geotechnical Control Office
Chan Mr P.F., Civil Engineering Office
Chan, Mr J.J.T., Civil Eng. Services Dept. (Dev. & Airport)
Chan, Mr V., Scott Wilson Kirkpatrick & Partners
Charlier, Mr P., Dredging International NV
Cheung, Mr P.C.T., Geotechnical Control Office
Cheung, Mr T., Dames & Moore
Chien, Mr D., Pioneer Concrete Group
Childers, Mr H.D., Binnie & Partners
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Chow, Mr L.L., Gammon Construction Ltd
Chui, Mr K.F., Geotechnical Control Office
Chung, Mr E.K.F., Binnie & Partners
Chung, Mr Y.L., Territory Development Department
Clover, Mr A., Freeman Fox Ltd.
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Cox, Mr D., Environmental Protection Dept.
Daley, Mr J., Gammon Construction Ltd
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NEWSLETTER Published regularly, bi-monthly from November 1982 to November 1985, quarterly from March 1986.

Vol. 1 (7 issues) 1982-3; Vol. 2 (6 issues), 1984; Vol. 3 (6 issues), 1985; Vol. 4 (4 issues), 1986; Vol. 5 (4 issues), 1987.

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