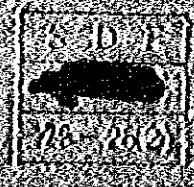
THE REPUBLIC OF SINGAPORE

REPORT
ON
THE STUDY OF FILL MATERIALS FOR RECLAMATION PROJECTS IN SINGAPORE'S TERRITORIAL WATERS

MARCH 1979

JAPAN INTERNATIONAL COOPERATION AGENCY



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PREFACE

In pursuant to the agreement reached between the Government of the Republic of Singapore and the Government of Japan concerning the conduct of a study on filling materials required for the reclamation project in Singapore's territorial waters as part of overseas technical cooperation of Japan, the Japan International Cooperation Agency (JICA) carried out a technical study.

JICA organized a steering committee headed by R. Nakamura, Director of the Yokohama Investigation and Design Office, the Second Construction Bureau, Ministry of Transport and survey team comprising engineers of Ocean Consultant, Japan and Kokusai Aerial Surveys, and dispatched experts to Singapore to carry out the field survey.

After returning from the field survey, the team analyzed and examined in Japan the information and data obtained in Singapore and has completed the present report for submission to the Government of the Republic of Singapore. I hope the present report will be found to be useful for the development of technology in the field of reclamation in Singapore.

I would like to express my heartfelt appreciation to the Government and the people concerned of Singapore for their close cooperation and assistance extended to the survey teams.

March, 1979

Shinsaku Hogen
President
Japan International Cooperation Agency
Tokyo, Japan

Letter of Transmittal

Mr. Shinsaku Hogen
President
Japan International Cooperation Agency

Dear Sir,

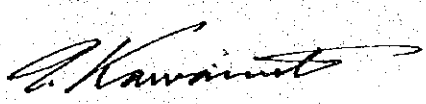
It is my great pleasure to submit herewith a report on the Study of Fill Materials for Reclamation Projects in Singapore's Territorial Waters, which has been prepared by Ocean Consultant, Japan, Co., Ltd. in accordance with the Scope of Work provided by the Japan International Cooperation Agency.

I would like to express my deepest appreciation to the Housing and Development Board, the representative authority of the Government of Singapore for this study, and various government organizations for their unlimited cooperation, assistance and warm hospitability extended to us during our stay in Signapore.

My indebtness is also great to the Japan International Cooperation Agency, the Ministry of Transport, the Ministry of Foreign Affairs, the Embassy of Japan to the Republic of Singapore, and the Port Bureau of Osaka Municipal Office that have given us valuable suggestions and assistance in preparing the report.

Sincerely yours,

March 15, 1979



Isamu Kawamoto

Leader of Consulting Team

Vice President
Ocean Consultant, Japan, Co., Ltd.

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I. SUMMARY

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SUMMARY

[1] RECLAMATION PROJECTS IN SINGAPORE

The Housing and Development Board (H.D.B.), the Jurong Town Corporation (J.T.C.), and the Port of Singapore Authority (P.S.A.) have reclaimed lands of over 3,000 ha to date.

H.D.B. has completed a series of reclaimed lands from Phase I to Phase V along East Coast and is carrying out further Phases VI and VII at present. In Phase I to Phase IV reclamation projects, hill-cut soil of 44 million cubic meters from Siglap Plain and Bedok Reservoir sites has been used as the fill materials, while in Phase V marine sand from the sea bottom has been used.
In Phases VI and VII cut soil from Tampines hill is going to be used.

J.T.C. has been carrying out reclamation from landside by using hill-cut soil mainly obtained at Tuas area. Recently it carried out reclamation projects at Seraya and Ayer Merbau using hydraulically dredged sea bottom sand.

P.S.A. has been reclaiming coral reefs mainly at Southern Islands using marine sand. P.S.A. is executing a large-scale reclamation project at Changi for the new internation airport, which is now almost completed.

As mentioned above, reclamation in Singapore has been carried out either with hill-cut soil or marine sand dredged from the seabed.

[2] SITE INVESTIGATION

The sites of the present site investigation havebeen selected at Outer Shoal and Off-shore Changi from the view point that fill material for reclamation is expected to be found judging from the boring data and geographical features of the sea bottom, that the areas are considered to have typical sea bottom soils of Singapore, and that the areas have not been investigated in the past.

The site investigation consisted of sonic prospecting, magnetic detection, and borings.

Approximate quantities of the field work and main equipment used in the field work are as follows :–

	Quantity	Main Equipment
Sonic Prospecting	Approx. 70 km	Sonostrator
Magnetic Detection	Approx. 45km	Flux Gate Type Magnetometer
Boring	11 boreholes	Rotary Boring Machine

[3] SEA BOTTOM SOIL IN SINGAPORE'S TERRITORIAL WATERS

"Geology of the Republic of Singapore" published by the Public Works Department in 1976 provides comprehensive geological information of the mainland of Singapore and her islands. On the other hand, the geology of the sea bottom in her territorial waters has not yet been put together systematically.

The consultant has classified and discussed the borehole data of the sea bottom both provided by the Singapore government authorities and obtained from the present investigation.

The locations of the past borings are not uniformly distributed over the territorial waters and considerable difference in soil condition in various areas is recognized.

From the past boring data the following will be summerized.

The sea bottom in the territorial waters is generally of soft marine clay. The marine clay is, in some western parts, especially around islands,covered with coral. It is in some parts overlain by loose sand varying in thickness.

In the western part, below the marine clay is seen layers of stiff clay and hard clay, which are considered weathered shale. Hard shale is reached generally at a depth of A.C.D. -15 m to -30 m.

In the eastern part, the marine clay, which is normally much thicker than in the western part, is underlain by old alluvium layers which are usually of medium to dense clayey sand, stiff to hard clay or clayey silt, etc.

In Sisters' Shoal and Raffle's Shoal a considerable amount of sand is seen. But the amount is not known because there are no borehole data which show the lower limit of the sand and also a great amount of sand has been exploited for various projects up to the present.

The result of the present investigation shows that under the sea bottom at Outer Shoal is a thick marine clay layer underlain by old alluvium, the top of which is at around A.C.D. -30m.
It also shows that in off-shore Changi there is an old alluvium hill, the top level of which is A.C.D. -6 m to -9 m. On this hill there is no marine clay but a thin layer of loose sand. The outside area of the hill has more or less the same strata as Outer Shoal.

The result of the magnetic detection shows that there are a considerable number of magnetic anomaly points both in Outer Shoal and off-shore Changi.

[4] STUDY ON METHODS & COSTS OF DREDGING & RECLAMATION

There are varieties of dradging methods.
Among these, cutter suction dredgers are most widely used in Japan, because they are capable of dredging almost any kind of material from hard to soft of a large quantity, and moreover they are capable of continuous operation. In reclamation in Japan, direct discharging system is the most commonly used method. Another method, which is also widely used in Japan, is dredger-bargeline system.

Now the seabed soil in Singapore, as discussed in Chapter 3, generally consists of soft marine clay, underlain by old alluvial layers such as clayey sand layers or stiff clay layers. In some limited areas loose sand is seen on top of the marine clay. Since the quantity of loose sand is limited, other materials such as old alluvial clayey sand would have to be utilized.

On the other hand, from the view point of dredging capability and economy, the N-value (number of blows in S.P.T.) of the material to be dredged would be limited to 40.
Therefore, fill material would be narrowed down to the following three kinds.

a. Marine clay
This is available in large quantities. The use of this material for reclamation is possible even if its nature as a fill material is of low grade.

b. Clayey sand with N-value less than 40.
This material contains large percentage of sand and is usable as a fill material of good quality.

c. Stiff clay with N-value less than 40.
The characteristics of this material will be rather inferior to the clayey sand. But this can be used as a sufficiently good fill material.

Since it is not practicable to use clayey sand and stiff clay alone because they are usually covered by a thick marine clay layer, mixed usage of the three will have to be considered. In this case the direct discharging system and the dredger-bargeline system will be the most favourable ones, as is the case in Japan.

Therefore, a comparison of the two systems has been made by estimating the cost of each system and it has been concluded that the direct discharging system is most favorable for Singapore. It is believed that the most recommendable way of reclamation is the direct discharging system by selecting a borrow area where a cutter suction dredger can dredge and send the seabed material to the reclamation site in such a manner to enable the dredger to make most economical production.
If the borrow area can be utilized as a turning basin or a navigational channel in future, it can be

economical even if it is rather far from the reclamation site.

Among the three kinds of materials, marine clay is available in the largest quantity and cost of dredging and transporting is the lowest. It contains, however, problems of ground weakness and settlement due to consolidation.

The second material, clayey sand, contains a large percentage of sand.
A reclaimed land filled with this material will have a good quality. The cost of dredging and transporting of this material is estimated about twice that of marine clay.

The third material, the old alluvial stiff clay, will also be a fairly good material for reclamation as compared to marine clay because it is deposited in Jumps, through there are some unknown factors to be solved in using this alone or using this with marine clay as fill materials. The cost of this material is estimated about three times that of marine clay.

When a mixture of different kind of materials are dredged and discharged into reclamation site, the particles constituting the materials tend to segregate and settle separately, i.e. larger particles near the outlet of discharging pipeline and smaller particles near the overflow weir. By making use of this nature a land of good quality is obtained as well as a swampy land consisting of clayey soil of a high water content.

Where the direct discharging system is applied to a huge reclamation area, as large as several hundreds hectares, it is recommended that the whole reclamation area be divided into several lots by inner temporary embankment and completed one by one. The size of each lot should be decided considering the dredgers' capacity in such a manner that the lot can be reclaimed in one or two years of time.

In order to achieve this, it is necessary to install trestles for the pipeline in the reclamation area at an appropriate spacing (usually 100 m to 200 m), prior to the dredging operation.

In planning a reclamation project, soil investigation in both reclamation site and borrow area, magnetic detection survey in the borrow area to search dangerous obstacles, removal of those, effect of dredging to the coastline due to the change of littoral current, and the study of fill material should be carried out, besides the design of revetment, temporary embankment, etc. or study of settlement due to consolidation and suitable soil improvement if necessary.

[5] STUDY ON THE GROUND CONDITION OF RECLAIMED LAND BY HYDRAULIC MEANS

As discussed in the previous Chapter, the land reclaimed with various kinds of materials by hydraulic dredgers tends to separate into a sound area and a muddy area. As to the former, there will be no

need to comment here since it will be the same land as obtained in Changi reclamation.
The latter, the muddy ground, will be discussed here. The soil of such ground has usually very high water content. In Japan, it takes about two years or more to get dried enough for a man to walk on, for drying process is eminent only in summer. Since such ground has, even dried, no trafficability for vehicles, surfacing soil 50 cm to 1 m in thickness should be placed.

In Japan, there are various methods for this purpose, such as rope-net method.
In case of Singapore, fortunately, the sunlight is strong, the temperature high, and the land is blessed with wind, it is considered that the drying is remarkable and any special method to place the surfacing soil will not be necessary.

A reclaimed land using clayey material such as marine clay has a ploblem of settlement due to consolidation. The amount of the settlement is dependent on the subsoil condition of the reclamation site, the characteristics of fill material, method of dredging and reclamation, and drainage condition in consolidation process. In general, the rate of settlement is great in the first one year or two, but decreases gradually until it approaches a limiting value.

The reclaimed land with soft soil, when the surfacing soil is placed, can be used as a park or a green zone without any subsoil improvement. For comparatively light structures to be built on such land, a simple subsoil improvement work will be necessary. For heavy structures, conventional pile foundation will have to be used. In this case proper measures must be taken against uneven settlement between the piled part and the part without piles. This can be dealt with by partial subsoil improvement.

Among many subsoil improving methods, preloading and drainage by means of vertical drains are most widely used and effective techniques for such soft reclaimed land.

(6) EXAMPLES OF RECLAMATION PROJECTS USING SOFT SEA BOTTOM MATERIAL IN JAPAN

In Japan, many reclamation projects have been carried out using sea bottom soils as fill material. Such projects have been conducted in large waterfront industrial regions such as Tokyo, Osaka, Nagoya, Yokkaichi, etc. The seabed of those regions is mostly of soft clayey soil and many reclaimed lands are made of clayey soil.

Among these, two projects have been chosen and discussed here.
The first is the reclamation project at Osaka South Port. About 70 percent of the whole reclaimed area amounting to 930 hectares consists of alluvial silty clay dredged hydraulically from the near-by sea bottom.

The surface of it was left for drying improved for nearly two years and then surfacing soil was placed. The subsoil of the reclaimed land has been improved using sand drains and other methods, with the exception of the area for parks or green zones. Now 80 percent of the whole reclamation is completed and most of the completed land is being utilized for housing, port facilities, etc.

The second example is a reclamation project for a steel mill at Fukuyama in Hiroshima Prefecture. The land here has been reclaimed from the sea by dredging sea bottom soft silt, and sand with gravel or hard clay under it mainly by cutter suction dredgers. The area where important structures were to be built was reclaimed with sand with gravel or hard clay. The other area was reclaimed using soft silt. On this reclaimed land of about 872 hectares, an integrated steel mill has been completed. It has been producing crude steel and other steel products for more than ten years.

II. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS AND RECOMMENDATIONS

Following the study on the fill materials for future reclamation in Singapore, the below-listed conclusions and recommendations have been drawn.

1. To make use of hill-cut soil for reclamation is an ideal method, both economically and technically, because it simultaneously provides two areas. It is considered, however, that Singapore will experience a shortage of hill-cut soil for reclamation in the near future.

2. Judging from past and present soil investigation data, there may be some sea bottom sand of a limited quantity in some limited areas. If so, however, it is considered that in Singapore's territorial waters it would not be sufficient for the requirement of the intended future reclamation.

   The existence of sea sand at deeper levels can not be definately commented on at this stage because of lack of investigation data.

3. Sea bottom sand is now a precious natural resource. It is recommended that the utilization of this material should be limited for special purposes such as revetment or artificial beaches.

4. Characteristics of seabed materials depend largely on areas.
   However, in general, the surface layer is of marine clay, below which old alluvial clayey sand (inclusive of sandy clay, silty sand, etc. –hereinafter called 'clayey sand') and partially stiff clay or hard clay of old alluvium.

   At places, the marine clay is overlain by a loose sand layer varying in thickness, which has been used as the fill material in past reclamation projects. Since sand is scarce, the utilization of the other materials for reclamation will have to be considered.

5. Marine clay exists in large quantities all over the territorial waters. Reclaimed land filled with marine clay, however, has small bearing capacity and has a problem of settlement due to consolidation.

   Clayey sand contains a large percentage of sand and is considered good material for reclamation. The limit of N-value (Number of blows per foot of penetration in the standard penetration test) for economical dredging should be forty (40). Reclaimed land consisting of this material would prove very satisfactory.

   Stiff clay is also considered as a fairly good fill material compared to marine clay. There are, however, some unknown factors in using stiff clay alone or with marine clay as a fill material, since there have been very few such cases and the nature of the ground (e.g. parameters of consolidation, bearing capacity, etc.) consisting of such a fill is difficult to predict. The limit of N-

value for economical dredging of this material should also be forty (40).

6. Since clayey sand and stiff clay are covered with marine clay, it is not practicable to carry out reclamation only with these materials. Marine clay should also be used with them.

7. The unit cost of dredging and hauling of materials was estimated as in the case of hydraulic dredging. The unit cost of the clayey sand with N–value around 40 is approximately twice that of the marine clay, while that of the stiff clay with N–value around 40 is about three times that of marine clay.

8. Comparison has been made of various dredging methods.
It has been concluded that the most recommendable method of reclamation for Singapore is the direct discharging of the dredged material by a cutter suction dredger for all of the above-mentioned three materials.

9. When the three kinds of materials are dredged and discharged through a pipeline into a reclamation area, coarser particles normally settle near the outlet of the pipeline and finer particles near the overflow weir. In this situation, stiff clay is discharged in lumps into the reclamation area. Therefore, we get two types of ground conditions.

   Softer areas of the land are generally used for such purposes as road, parks and green zones which do not require the ground resisting strength nor cause any problem of settlement, in comparison to the more sound land used for such facilities as buildings.

   Therefore, it would be worth planning to employ the above-mentioned method of reclamation in drawing up the appropriate layout of heavy structures on sound parts of the land, and light-weight structures, road, or parks, on softer areas of the land.

10. The surface layer of the seabed in Singapore is generally of marine clay. If reclaimed land is created on such a seabed with fill material of good quality, the problem of settlement still exists. If marine clay is used as fill material, the settlement due to the consolidation of the fill material will be added to that of the existing marine clay. The improvement of the fill material would be easily conducted.

11. In Japan, much reclaimed land has been created on seabeds of soft marine clay using marine clay of nearby sea bottom as the fill materials.
Most of these areas have been successfully utilized for industries and housing with the help of various techniques.

12. The important thing in the case of reclamation only with marine clay is to harden the surface of the fill material as quckly as practicable.

In Singapore, the hardening of surfaces is considered to be rather fast because the rate of evaporation is great thanks to strong sunshine, high temperature, and wind.

13. Since the ground of marine clay fill has, even with the surface hardened, no trafficability, surfacing soil of good quality should be placed. The thickness of the surfacing soil depends on the required bearing capacity of the ground surface. Usually 50 cm or 1 m would be sufficient for ordinary constructional equipment to travel upon.

In the case of the surface hardening process being slow, as in Japan, special techniques such as rope-net method are used to help place the surfacing soil on very soft ground. These methods would not be necessary in Singapore.

Once the surfacing soil is placed, the ground can be used without any improvement as a park or a green zone, where settlement is not so important.

14. The amount of the settlement, due to the consolidation of the fill material of marine clay, depends on the characteristics of the fill material, the method of dredging and reclamation, and the thickness of the fill material. The amount should be estimated in the planning stage through thorough investigations and studies.

Generally the settlement proceeds in a considerably rapid rate in its early stage, and decreases its speed with the lapse of time, finally becoming minimal. Where the thickness of the soft soil is great, the process of the consolidation lasts for a long time. Where the surfacing soil is thin, the increase in the cohesion of the soft fill material can not be expected.

Therefore, an appropriate subsoil improvement would be necessary, depending on the time and purposes of utilization of the land.

15. When a rather light structure is built on such reclaimed land, simple subsoil improvement may be enough. For heavy structures, pile foundation would be required as performed in the past, in which case negative friction must be taken into consideration in the design.

16. When roads or other structures which sustain relatively small loading are built on such reclaimed land, the problem of the bearing capacity of the ground can be dealt with only by placing soil of good quality with an appropriate thickness.

In case of roads, there may appear a difference in level between the fill part and the structure part like a culvert or an abutment. This can be solved by partial subsoil improvement to accelerate consolidation.

Where an underground facility like sewer, water main or gas pipeline is installed in an early stage of consolidation, due consideration should be taken for a large settlement. In Japan, there are some cases where a temporary facility was installed during the early stage of consolidation and was finally completed as a permanent one when the settlement has slowed down.

17. One of the important factors to achieve economical reclamation is the distance between the borrow area and the reclamation site. If the borrow area could be selected in the future navigational channel or the turning basin, it would be economical as a whole even if the borrow area is rather distant.

18. When a borrow area is selected near the coastal line, care must be taken against the erosion of the coast by wave action. This could be avoided by selecting the borrow area at reasonable distance from the shore, since waves are generally not high in Singapore.

19. There are some areas where tidal current is strong. In such areas, the borrow area should be selected at such a place that the change in the sea bottom profile by dredging should not affect the tidal pattern in the area unfavourably.

20. There is a possibility of some explosives remaining in the territorial waters since the war. It is, therefore, necessary to perform magnetic detection prior to dredging or borrowing of the fill material, and if any explosives be found they should be of course removed before commencement of actual dredging work.

21. In planning the proper reclamation scheme in the future, detailed investigation and adequate survey of the fill material will further be required on the respective scheme prior to its realization.

III. MAIN REPORT

CONTENTS OF MAIN REPORT

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INTRODUCTION

The Government of the Republic of Singapore has given the high priority to the development of housing and land as the national projects, and has been actively carrying out very extensive coastal reclamation.

Today the Republic has a population of about 2.3 million, which is anticipated to reach to 2.7 million in 1990 even at lower annual rate of increase. In consideration of its total area of 588 sq. km, almost equivalent to that of Awajishima Island of Japan, the annual rate of rapid increase would bring about keen demand for land. On the other hand, Singapore is eager to invite modernized international industries, and in order to encourage the industrial development the necessity of land will be accelerated.

Therefore, it seems that the demand for land–first for residential, second for commercial and industrial, and third for social and recreational purposes–will increase more and more in the future.

For the past ten years, the Government of Singapore has reclaimed its land mainly by earth fill from the land and sand from the seabed.

The low undulatory hills over the country of 20 - 40 m above the sea level have been excavated, flattended and developed to be used for residential and industrial area. At the same time the excavated soil has been utilized for reclamation of seaside swamp or of the seabed. However, most part of these hills have been already excavated and the earth fill from the land is substantially exhausted, while most of the sand deposits on the sea bed also been utilized for previous reclamation projects and are now coming to its limit.

The possibility of obtaining the fill materials from these sources is not bright, and therefore, it seems to be critical to study some comprehensive methods to make use of such materials from the seabed as have never been used, together with effective use of the sand resource of the limited quantity.

In Japan, extremely wide area of land has been reclaimed from the sea corresponding to the industrial deveropment after the war, and through these achievement various kinds of technical experience in reclamation have been accumulated. These technical experiences could be very useful to Singapore.

On account of this, the Government of Singapore has requested the Japanese government to provide technical assistance in studying useful fill materials from the seabed in the territorial waters of Singapore, and the Government of Japan, in response to the request, has decided to conduct a relevant study through the Japan International Cooperation Agency (JICA).

In June, 1978, at the start of the study, JICA dispatched to Singapore a Preliminary Survey Team headed by Mr. R. Nakamura, Director of Yokohama Investigation and Design Office of the Ministry of Transport (MOT). The Team and the Housing and Development Board (HDB) of the Ministry of National Development representing the Government of Singapore for this study have set up the Scope of Work for this study.

For the purpose of performing the Scope of Work, JICA has set up a Steering Commitee and a Consulting Team. The Committee members and the Consulting Team jointly carried out general investigation from November to December, 1978, while soil investigation was also carried out in accordance with the Scope of Work.

Under the supervision and advice of the Steering Committee, the Consulting Team has drawn up this report based on the results of this field survey.

The Steering Committee and the Consulting Team consist of the below-listed members respectively:–

1. Steering Committee

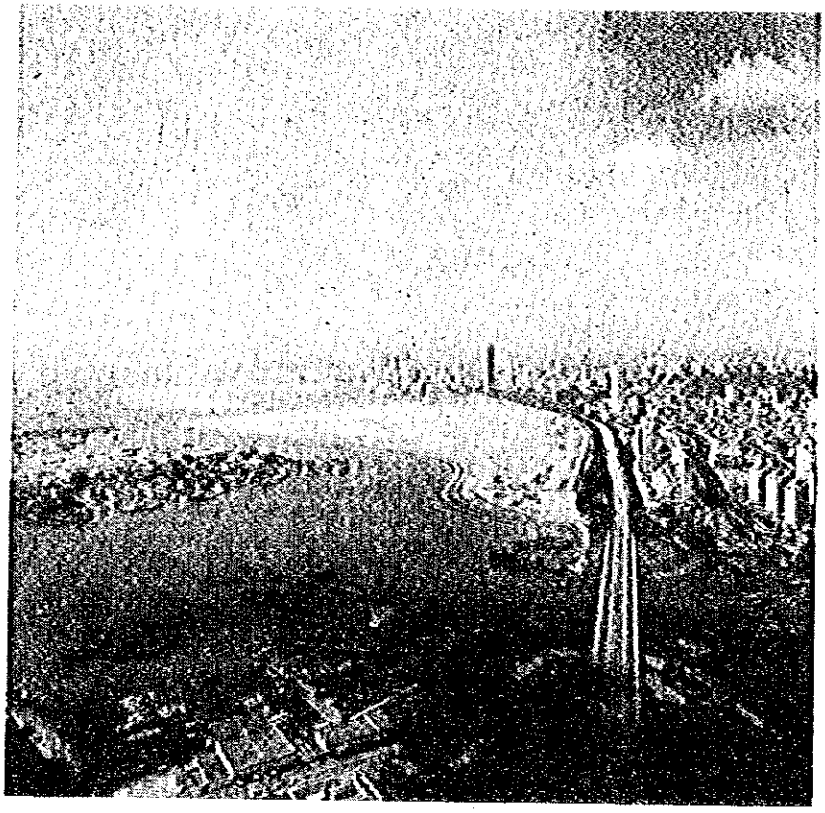
Leader	
R. Nakamura	Director of Yokohama Investigation & Design Office, MOT.
M. Terashi	Chief of Soil Stabilization Lab., Port and Harbour Research Institute, MOT.
M. Maeda	Special Assistant, Yokohama Investigation & Design Office, MOT.
M. Kiyama	Planning Div., South Port Development, Port and Harbour Bureau, City of Osaka
H. Nishijima	Social Development Cooperation Department, JICA.

2. Consulting Team

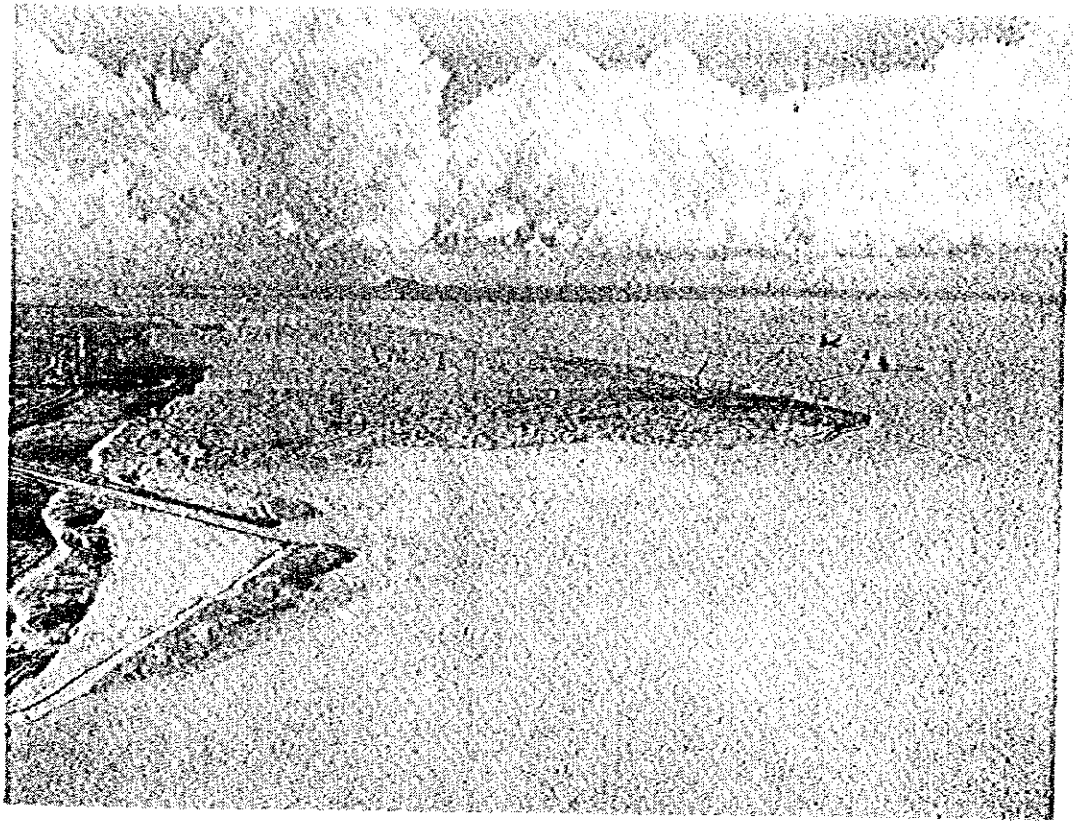
Leader	
I. Kawamoto	Vice President, Ocean Consultant, Japan, Co., Ltd.
Y. Kanesato	Chief Civil Engineer, Ocean Consultant, Japan, Co., Ltd.
M. Niwa	Civil Engineer, Ocean Consultant, Japan, Co., Ltd.

The Singapore Government representatives coordinating this study are as follows:–

Leader	
Chew Seong Yean	Chief Civil Engineer, Housing and Development Board
John Wei	Principal Civil Engineer, Housing and Development Board
Ho Wah Hin	Civil Engineer, Housing and Development Board



East Coast Reclamation, Phase V



Major Reclamation at Changi

RECLAMATION PROJECTS IN SINGAPORE

Reclamation project is one of the national projects of the high priority and importance in the Republic of Singapore.

It would be worth admiring when we have a look at such harmonious scenery as towering buildings for housing, green parks, well-planned net-work of roads, and colourful recreational facilities at the seashores completed on the reclaimed land around the country. The ground for further development of the Republic will be more strengthened by the subsequent reclamation plans and schemes now being undertaken, in addition to the reclaimed areas which have been completed under the present scheme.

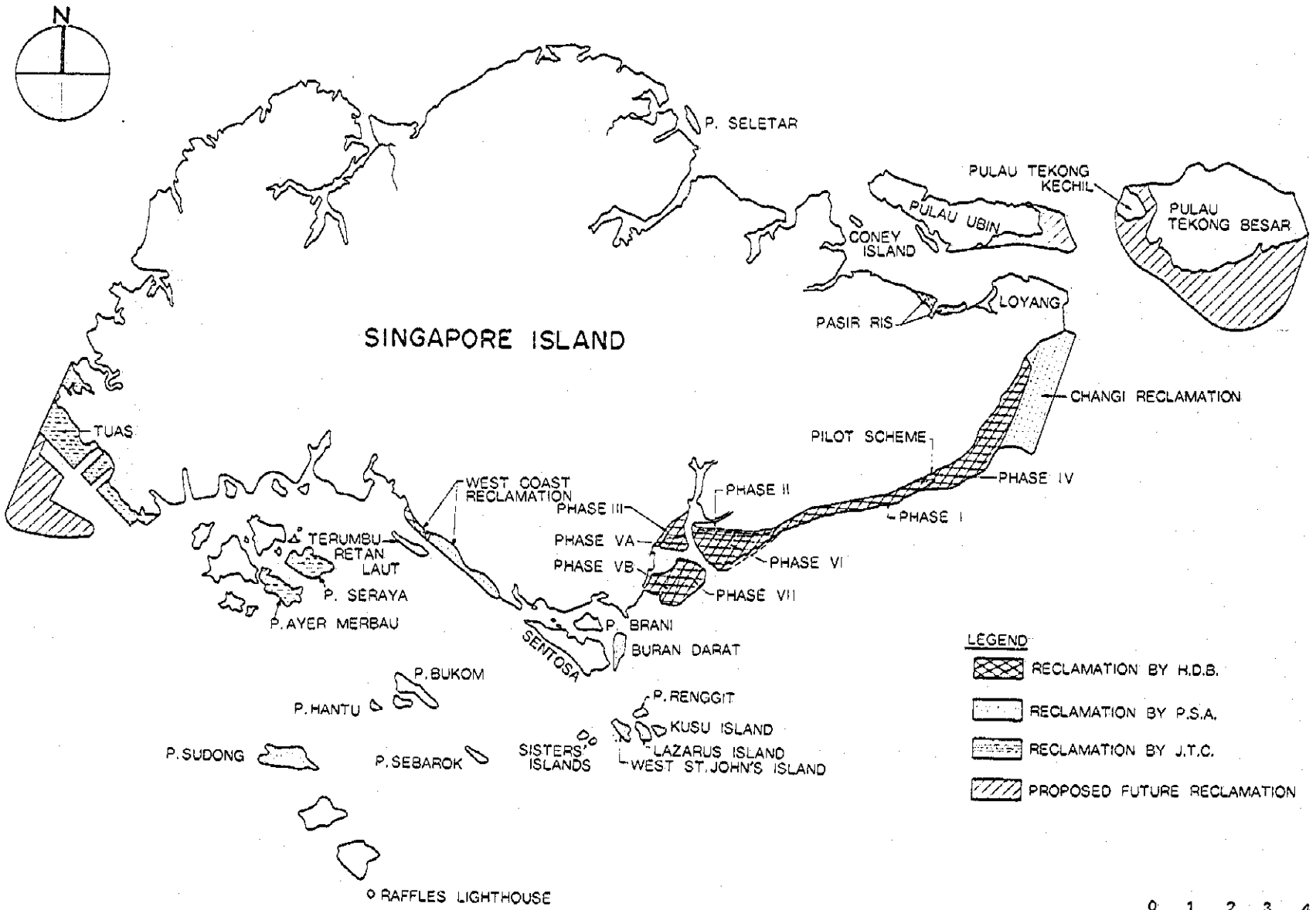
Some explanation is made hereunder on the reclamation projects in Singapore carried out in the past and to be done in the near future as well:–

1-1 Reclamation Projects Completed or Being under Construction

Almost all of the reclamation schemes have been undertaken by the three governmental organizations, the Housing and Development Board (H.D.B.), the Jurong Town Corporation (J.T.C.), and the Port of Singapore Authority (P.S.A.). The total reclaimed area already completed by these three organizations comes to over 3,000 ha. Table 1-1-1 is a list of whole these reclaimed areas, the locations of which are indicated in Fig. 1-1-1:–

H.D.B. has so far completed Phase I to V of its scheme mainly on the East Coast and is carrying out Phases VI and VII at present.

As to Phase I to IV among this scheme, hill-cut soil was excavated from Siglap Plain and Bedok Reservoir sites by way of bucket wheel excavators, transported from landside by conveyors and barges, and was used for the reclamation work, the total quantity of which amounted to 44 million cubic meters.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P. SELETAR
PULAU TEKONG KECHIL
PULAU UBIN
PULAU TEKONG BESAR
CONEY ISLAND
LOYANG
PASIR RIS
SINGAPORE ISLAND
CHANGI RECLAMATION
PILOT SCHEME
PHASE IV
PHASE I
PHASE II
PHASE III
PHASE VA
PHASE VB
PHASE VI
PHASE VII
TUAS
WEST COAST RECLAMATION
TERUMBU RETAN LAUT
P. SERAYA
P. AYER MERBAU
P. BRANI
BURAN DARAT
SENTOSA
P. BUKOM
P. HANTU
P. RENGGIT
KUSU ISLAND
LAZARUS ISLAND
WEST ST. JOHN'S ISLAND
SISTERS' ISLANDS
P. SUDONG
P. SEBAROK
RAFFLES LIGHTHOUSE
LEGEND
RECLAMATION BY H.D.B.
RECLAMATION BY P.S.A.
RECLAMATION BY J.T.C.
PROPOSED FUTURE RECLAMATION
SCALE 0 1 2 3 4 MILE
0 1 2 3 4 5 6 KILO METER

Fig. 1-1-1

Table 1-1-1 List of Reclamation Works of the Presence & the Past

Project/Location of Work	Employer	Period	Total Cost (S$)	Awarded To	Reclamation Material	Reclamation Method
East Coast Reclamation Scheme Phase V at Telok Ayer Basin (154 ha.)	HDB	Apr. 1974 ~ Dec. 1977	106 million	Ohbayashi-Gumi Limited and Penta-Ocean Construction Co., Ltd.	Sea Sand	By Pump Dredgers & Barges
East Coast Reclamation Scheme Phase IV Bedok to Tanah Merah Besar (486 ha.)	HDB	May 1971 ~ Feb. 1976	44 million	China Engineers & Chin Ann Pte Ltd.	Hill-Cut Soil	By Onshore Excavators & Belt Conveyors (also Barges and Pump Dredgers for Phase III)
East Coast Reclamation Scheme Phase III Kallang River to Singapore River (67 ha.)	HDB	Mar. 1971 ~ Dec. 1975	23 million	Ohbayashi-Gumi Ltd.		
East Coast Reclamation Scheme Phase II Singapore Swimming Club to Tanjong Rhu (53 ha.)	HDB	Apr. 1970 ~ May 1971	10 million	Ohbayashi-Gumi Ltd.		
East Coast Reclamation Scheme Phase I Bedok to Singapore Swimming Club (405 ha.)	HDB	Apr. 1966 ~ Apr. 1970	45 million	Ohbayashi-Gumi Ltd.		
Reclamation of Pulau Seraya Off Jurong (175 ha.)	JTC	Oct. 1975 ~ Dec. 1978	35 million	Loh & Loh-Daioh Joint Venture	Sea Sand	By Pump Dredgers
Major Reclamation at Changi (653 ha.)	PSA	Feb. 1976 ~ Mar. 1979	230 million	Penta-Toa-Rinkai Joint Venture	Sea Sand	By Pump Dredgers
Dredging of Navigational Channel and Reclamation of Beting Sudong (243 ha.)	PSA	Oct. 1976 ~ Dec. 1978	45 million	Toa Harbour Works Co., Ltd.	Sea Sand	By Pump Dredgers & Barges
Site Formation Work on Pulau Ayer Merbau for Sumitomo Petro-chemical Complex (120 ha.)	JTC	July 1976 ~ Dec. 1977	21 million	Kajima Corporation	Sea Sand	By Pump Dredgers Barges
East Coast Reclamation Scheme Phases VI & VII Tanjong Rhu to Telok Ayer Basin (360 ha.)	HDB	Jan. 1979 ~ Jan. 1985	about 385 million	Ohbayashi-Gumi Ltd. & Rinkai Construction Co., Ltd.	Hill-Cut Soil	By Onshore Excavators & Barges
Pasir Ris Reclamation (44 ha.)	HDB	June 1978 ~ Oct. 1979	about 5.5 million	Tiong Seng Construction Pte Ltd.	Hill-Cut Soil	By Onshore Excavators & Dump trucks
West Coast Reclamation Off West Coast Road	HDB	Jan. 1975 ~ Dec. 1977	–	Several Contractors	Hill-Cut Soil	By Onshore Excavators & Dump Trucks
West Coast Redevelopment Scheme at Pasir Panjang	PSA	Nov. 1971 ~ Dec. 1975	12 million	Several Contractors	Hill-Cut Soil	By Onshore Excavators & Dump Trucks
Reclamation of Small Offshore Island and Reefs (about 192 ha. total)	PSA	–	about 54 million	Several Contractors	–	–
Reclamation of Tuas (400 ha.)	JTC	1973 ~ 1976	12 million	Tiong Seng Contractors Pte Ltd.	Hill-Cut Soil	By Onshore Excavators & Dump Trucks

HDB: Housing and Development Board JTC: Jurong Town Corporation PSA: Port of Singapore Authority

Under Phase V of the scheme, marine sand was obtained from several winning areas by low pressure hydraulic dredgers, loaded onto barges and transported to the reclamation site. A half of total 20 million cu.m. of the fill material was directly dumped by barges into the reclamation site, while the remaining half was deposited in the interim dumping area near the fill area until substantial completion of the surrounding permanent revetment, and then pumped into the fill area by pipe-line of the dredgers.

Under Phases VI and VII of the present scheme, hill-cut soil excavated from Tampines hill is to be conveyed by conveyors to off Bedok, loaded onto and transported by barges and filled into the reclamation area.

J.T.C. has been carrying out reclamation from landside by using hill-cut soil obtained at Tuas area, but recently performing the reclamation at Seraya and Ayer Merbau with sandy soil from the sea bottom by means of hydraulic dredgers.

P.S.A. has been reclaiming coral reefs mainly at Southern Islands in use of marine sand, and has executed reclamation of 650 ha. at Changi for a new international airport.

As mentioned above, reclamation works have been carried out either with hill-cut soil excavated from landside or with sandy soil dredged from the sea bottom, where hill-cut soil has been the most common fill material for reclamation in Singapore. This is really a helpful way to simultaneously achieve the dual aims of utilizing the excavated soil for reclamation and the land itself for housing and industrial areas, which has played a great role in developing the housing new towns and the estates for factories in Singapore.

At the same time, many reclamation projects have been achieved by J.T.C. and P.S.A. in use of marine sand as well which has been obtained at Sisters' Shoal, Johore Shoal and other sources in between the islands. Major projects among them are Reclamation at Seraya (175 ha.) and Ayer Merbau (120 ha.) executed by J.T.C., and Reclamation at Beting Sudong (243 ha.) and Changi (653 ha.) by P.S.A.

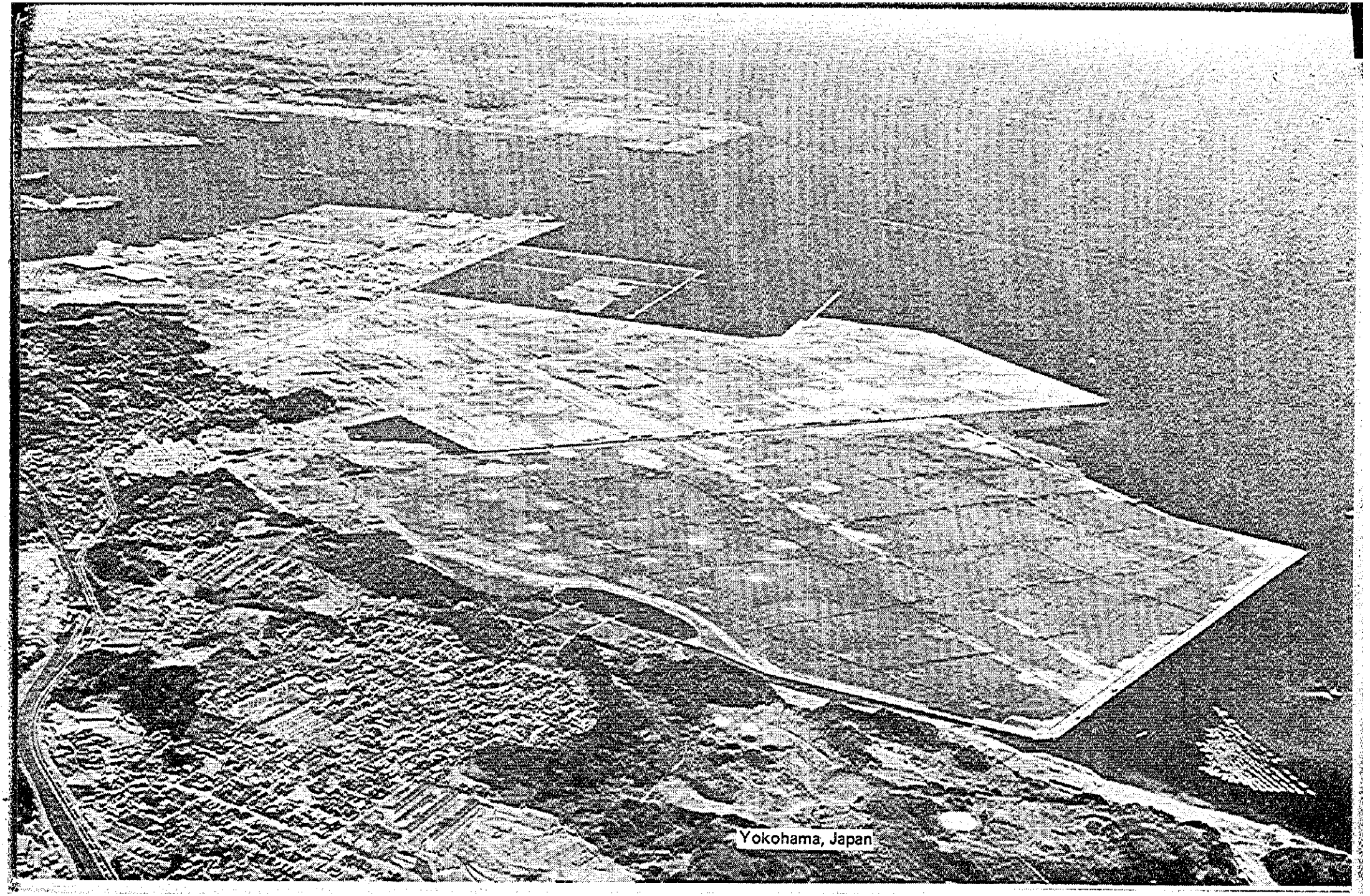
In all the cases, the sandy soil existing around the reclamation area was directly pumped up into the fill area, or the one borrowed from too distant sources for pumping up was loaded onto barges by a low pressure hydraulic dredger, deposited in the interim dumping area near the reclamation area, and finally pumped up into the fill area through the pipe-line of another hydraulic dredger.

1-2 Future Plans

The future projects are listed below in Table 1-2-1, based on the informations available at present:-

Table 1-2-1 Pending Reclamation Scheme and Future Plan

Projects	Scheduled Relamation Area	Period	Filling Method	Remarks
Reclamation Off Tekong	400 ha	60 months	Undecided	Pending
Relamation at Semakau	144 ha	40 months	Undecided	Pending
Reclamation at Tekong/Ubin	Unspecified	Undecided	Undecided	Future Plan
Reclamation at Tuas	613 ha	Undecided	Undecided	Future Plan


Yokohama, Japan

(2) SITE INVESTIGATION

It goes without saying that in order to study the fill materials in the territorial waters the best practice is to carry out borings and other essential investigations in her overall territorial waters, however, it is not practicable due to huge expenses and time incurred in such investigations.

This time the investigations are reduced to two locations based on the following points of view in order to assist in having a notion of the fill materials existing in Singapore.

2-1 Selection of Investigation Areas

Two areas, Outer Shoal and Off Changi, have been selected as the investigation sites from the following points of view:—

- The areas are considered to be of high potentiality of existence of the fill materials, reading the boring data in hand and geographic feature of the sea bottom.
- These areas are considered to represent the standard conditions and characteristics of the sea-bottom soil in Singapore.
- The investigation has never been carried out so much in these areas.

Fig. 2-1-1 indicates the locations of the sites investigated.

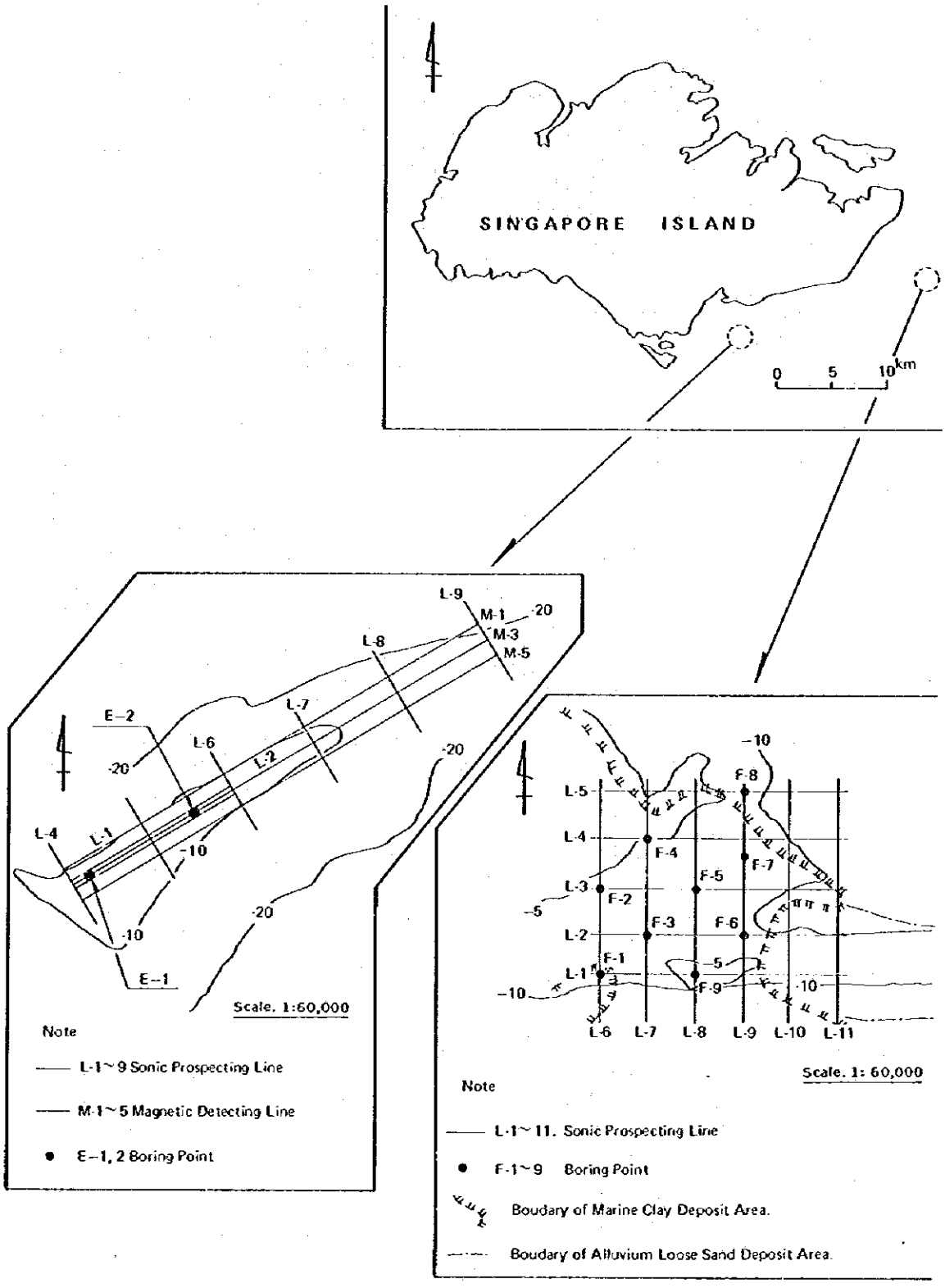


Fig. 2-1-1 Plan of Present Survey

2-2 Particulars of Investigation

The following three items of the site investigation have been performed in the under-mentioned ways:–

- Sonic Prospecting
- Magnetic Detection
- Boring

First, stratum condition of the sea bottom soil was estimated by means of the Sonic Prospecting. Approximate locations of borings were then decided based on the assumed stratum condition. The locations were finally decided at such positions where magnetic anomalous points did not appear based on the results of the magnetic detection carried out prior to the borings.

2-3 Scope of Investigation

2-3-1 Sonic prospecting

The sonic prospecting has been performed along the survey lines as shown in Fig. 2-1-1. Length overall of the lines counted as follows:–

Outer Shoal area	26.2 km
Off Changi area	43.6 km
Length overall	69.8 km

The under-listed equipments were used for the prospecting:–

– Sub-bottom profiler (sonostorator, model SP-3)

Maker :	Kaijo Electric co., ltd.
Sonic Pulse Frequency :	1 kHz ~ 10 kHz
Recording Range :	shallow . . . . . 0 ~ 25 m
	deep . . . . . 0 ~ 50 m
Recording Method :	linear line recording by time belt
Recording paper :	dry type
Oscillation :	electro pulse oscillation with transistor
Recording Speed :	80 mm/min. . . . . shallow
	40 mm/min. . . . . deep
Power Source :	100 V AC, 50/60 Hz, 2 kVA

– Distance Measuring Instrument 1 set
(Automatic distance meter: Audister)

Maker :	Shimada Physical & Chemical Industrial co., ltd.	
Type :	9D010, Master station	1 unit
	Slave station	2 units
Max. Measurable Distance :	20 km	
Max. Indication Distance :	99999.9 (6 digits) m	
Measurement Distribution Error :	±1 m	
Measurement Tolerance :	0.1 m	
Carrier Frequency :	8.5 GHz	
Antenna Output Power :	0.3 W (approx.)	
Antenna Directivity :	Master station horizontal	360°
	Master station vertical	15°
	Slave station horizontal	30°
	Slave station vertical	15°

– Tug Boat : 22.5 GT., 238 HP 1 No.

2-3-2 Magnetic detection

The magnetic detection has been also performed prior to the soil investigation in order to examine the possible existence of any explosives such as bombs and mines, for which the underlisted equipment was used:–

– Flux Gate Type Magnetometer 1 set

Maker :	Shimazu Seisakusho, ltd.	
Detecting Probe :	Type MB100	5 probes
6 Channel Controller :	Type MB100C-06	1 No
Sensitive Range :	±0.5, ±2, ±10, ±50 mG	
Accuracy :	Indicator, ±10% of each full scale value	
	Recorder, ±2% of each full scale value	
Output :	±1 V	

– Pontoon : 42.35 GT., 13.4 m x 7 m 1 No
(Non-ferrous structure)

– Tug Boat : 22.5 GT., 238 HP 1 No