From the above diagram it is easily seen that reclamation by grab dredger method is more expensive than that by cutter suction dredgers.

Further, the top level of the fill which allows direct dumping by barge is limited by the drafts of the barge and tug boat, and in order to place the fill over the level the materials must be unloaded from the barge and again be transported by some other means.

Since the dredging capacity of the Grab Dredger is usually less than a third the same of the Cutter Suction Dredger, fleet of the Grab Dredger of several times the numbers of the Suction Dredger will be required in dredging large volumes of the fill materials, which will cause great congestion of barge navigation and lowering of operational efficiency, and therefore is not practicable.

In conclusion of the above discussion, the direct pumping method by means of the Cutter Suction Dredger will be most recommendable for each kind of material when the transporting distance is within such distance as economical product is expected.

4-3-3 Reclamation by cutter suction dredger

Cutter suction dredging is a recommendable and economical method in dredging and transporting clayey sand and stiff clay with N-value of less than 40 as well as marine clay, if the dredged material can be discharged directly into the reclamation area from the borrow area.

It is economical to select the borrow area as near as possible to the reclamation area. It would be a good idea to select a borrow area in the future navigational channel or the turning basin. In this case, even if the borrow area is rather distant, it would still be economical as a whole.

In general, marine clay exists in a large volume and dredging and transportation cost thereof will be cheap, but it will cause settlement due to consolidation and the ground of the land will not be very strong.

Clayey sand with N-value of 40 is estimated to cost twice as much to dredge and transport as marine clay, yet reasonable solidity of the ground will be obtained because of its high sand content.

Stiff clay with N-value of 40 is estimated to cost about three times that of marine clay in dredging and transportation, yet will be useful as a suitable material because it will be dredged in lumps as experienced in past reclamation works.
This material, however, has some unknown factors in its mechanical feature, especially when it is used alone or with the marine clay as the fill material. Futher study on this matter will be necessary.

It is recommendable, however, to make use of marine clay for reclamation by dredging it together with clayey sand and stiff clay, since they are covered with marine clay and therefore it is not practicable to dredge clayey sand and stiff clay alone for reclamation.

When the dredged material is hydraulically discharged as stated above within the reclamation area surrounded by the revetment, the material will be separately deposited depending on the size of the segregated particles, that is, coarser particles will be deposited near the outlet of the pipeline and finer particles around the over-flow weir. In this way, if a large quantity of the material is hydraulically discharged in its entire quantity, the reclamation can be achieved in such manners as to separately obtain the area where the sandy soil and the hard lumps of clayey soil are collectively deposited and the another area where the small particles of the soil is mainly deposited with very high water content.

In order to expect the effect mentioned above, discharging pipeline must be so arranged that the expected material can be placed where desired. Since the dredging operation of a hydraulic dredger is continuous, it is essential that the pipeline be distributed over the reclamation area in such a manner that a desired material be placed at a desired area by diverting the flow to a specific outlet according to the change of material encountered at the dredging site.

Location of the over-flow weir(s) must be determined at such a place as the expected land will be obtained. An over-flow weir with stop-log is often used to control the outflow of overflowing water by raising the top level of the weir corresponding to the progress of the reclamation.

It must be noted that some of the very fine particles of the soil will flow out of the overflow weir during reclamation, against which some measures must be taken. The amount of the loss will depend on the square of the land, the progress of reclamation and the characteristics of the soil.

Where the direct fill by cutter suction dredgers is adopted in large squares of reclamation to the extent of several hundred ha, it is desirable to divide the whole reclamation area into several parts in consideration of the total capacity of the dredgers so that each part may be completed in one to two years' time.

Since it will take a long time before commencement of the work to have the permanent revetment completed all along the periphery of the whole area, temporary inner embankment is to be simply constructed to divide the area into such squares of parts that can be completed within the said time. In this way, reclamation work by the dredgers can be partly commenced prior to the completion of the whole revetment. Fig.4-3-2 shows explanatory sketches of the above procedures (NOT designed for practical use).

The temporary embankment is to be made as simply and cheaply as practicable because it would not affect the whole works too much even damaged or destroyed, though the periphery revetment must be sufficientry stable as the permanent structure.
In Japan, simple wooden cofferdams have been widely used as temporary embankments. In Singapore, stiff clay or sandy clay as well as hill-cut soil may be used for the purpose. The embankment can be mounded by means of depositing the coarse material falling down from the small holes opened at several places of the bottom side along the pipeline.

If the fill material is sand or sandy soil, the discharging pipeline of a hydraulic dredger can be simply placed just on the filled ground without any supporting frames in its extension. But in case the fill material contains silty soil or marine clay, it is difficult to extend the pipeline on the ground correspondingly to the progress of the work. The pipeline, therefore, will have to be distributed on trestles which are installed beforehand prior to the commencement of the dredging operation. The spacing of the pipeline is usually 100 m to 200 m depending on the dredging material.

Aggregate cost of reclamation in this case will be inclusive of those of the permanent revetment, the temporary embankment and the pipeline with trestles, if any, in addition to that of reclamation itself as examined in the previous section.

When a borrow area is selected near the coastline, care must be taken against the erosion of the coast by wave action.
This can be avoided by selecting the borrow area reasonably apart from the shore, since the wave in Singapore is generally not high. It must be considered, however, that the location of the borrow area is to be determined at such place as the coastline may not be damaged by disturbedly altering the tidal current along the coastline, because the tidal current is

fairly strong at some places in the territorial waters.

Here arisen the anxiety about the possible existence of some explosives remaining in the territorial waters which were dropped down during the war time. It is, therefore, required to perform the magnetic survey thereof and to remove the same, should any be found, prior to dredging the fill material.

Studies have been made in general on the useful material for the future reclamation projects, based on the results of the present survey and on the informations provided by the governmental authorities.

In planning the future reclamation schemes, further studies on the material will be initially required in details and for each individual project. The typical flow of the reclamation works by means of the cutter suction dredger is shown on the following chart, Fig. 4-3-3, though it will depend on the method applied to the reclamation project.

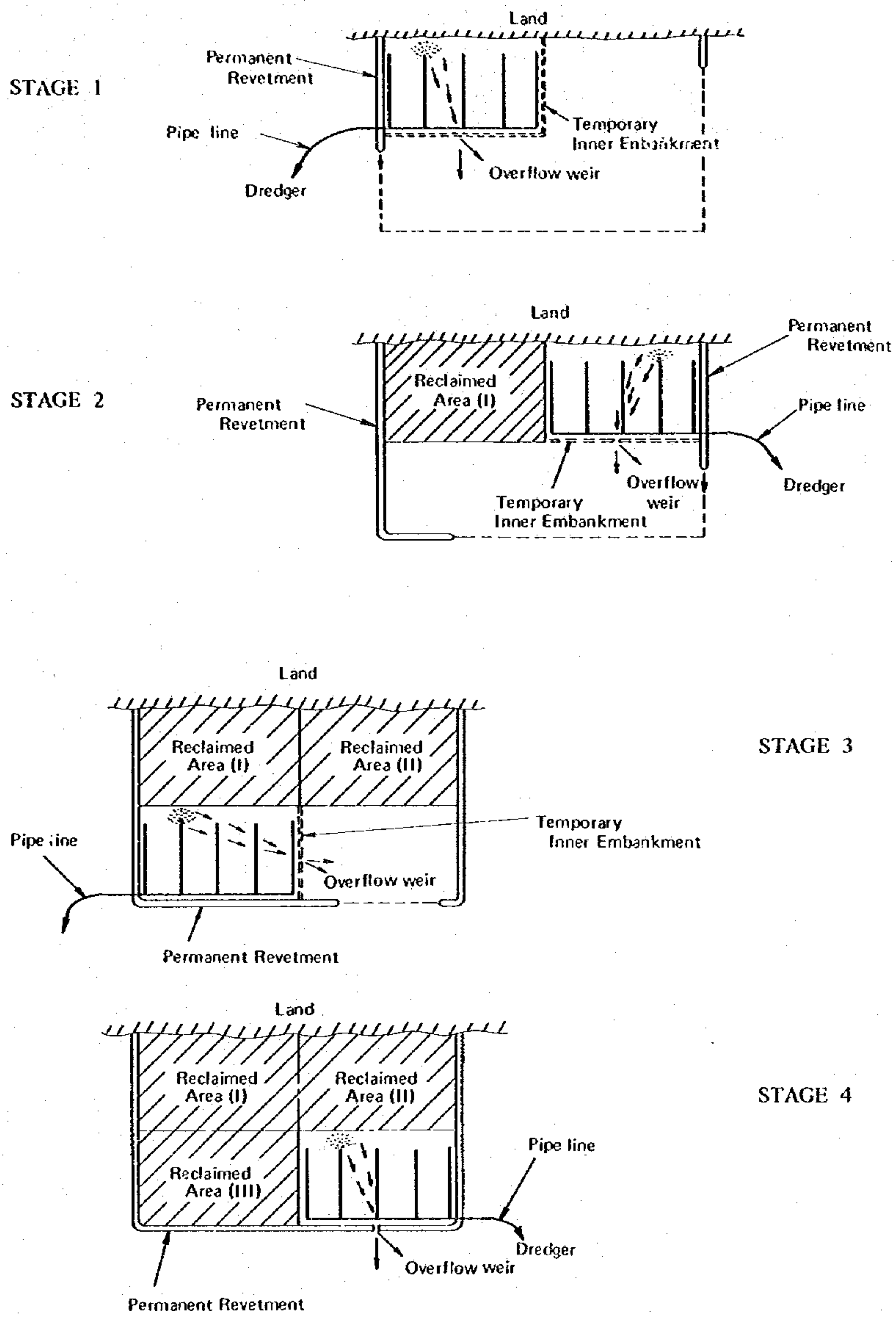
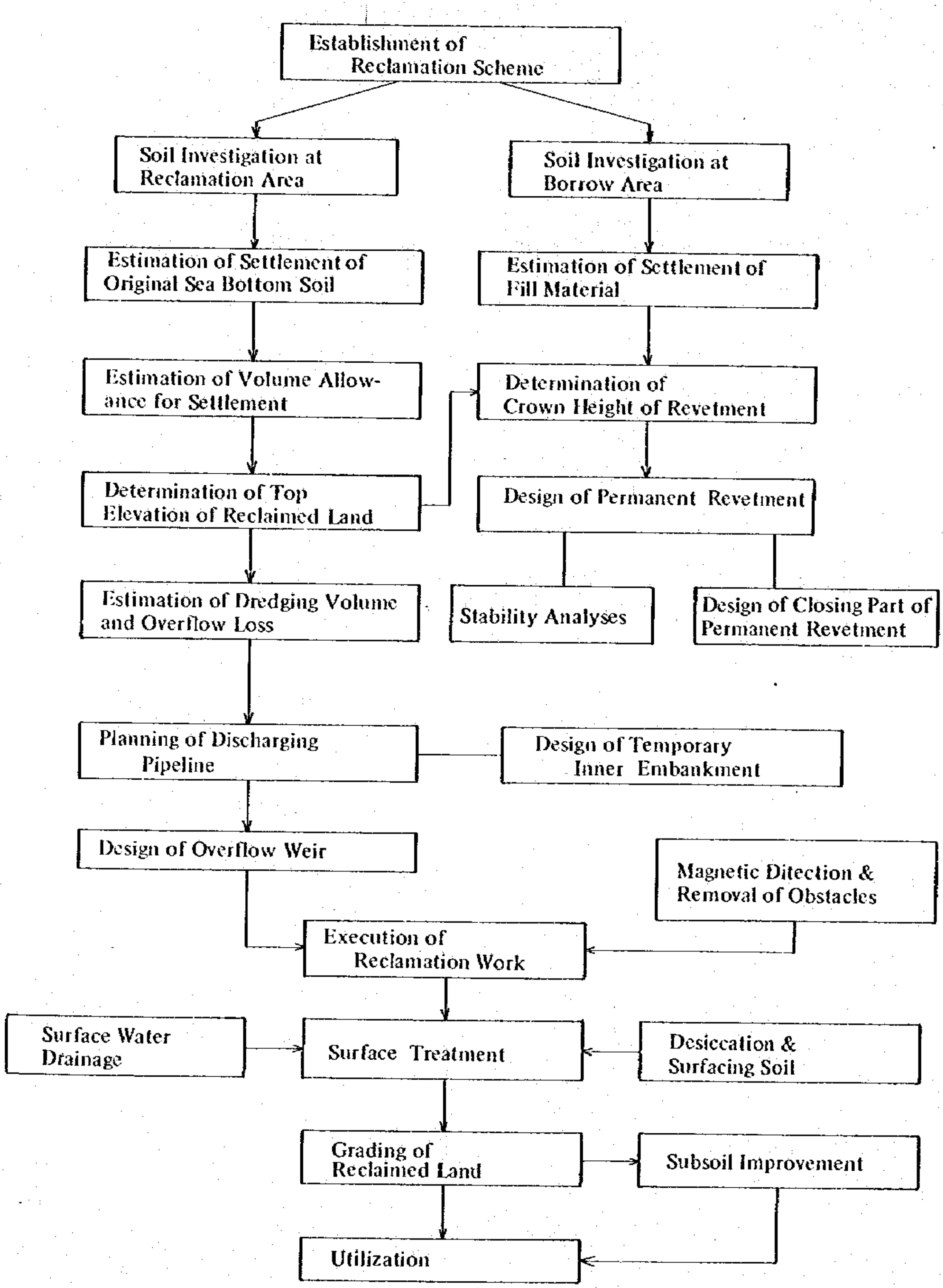



Fig. 4-3-2 Divisional Reclamation Procedure

Fig. 4-3-3 Typical Flow Chart of Reclamation Work by Cutter Suction Dredger




Nagoya, Japan

# (5) STUDY ON THE GROUND CONDITION OF RECLAIMED LAND BY HYDRAULIC MEANS

In Chapter 4 it has been concluded that the most suitable and economical method of reclamation for Singapore is the direct discharging into an enclosed area of sea bottom materials available in the vicinity of the area to be reclaimed, by cutter suction hydraulic dredgers. In this Chapter, the condition of a hydraulically reclaimed land, its problems, and the solutions to them will be discussed.

## 5-1 Condition and Problems of a Hydraulically Reclaimed Land

Reclamation Projects by direct discharging of sea bottom sand have been done in Changi and other places. In this type of projects coarser particles of the sand tend to concentrate near the outlets of the discharging pipeline and finer particles near the overflow weir. In a reclamation project without embankment finer particles such as fine sand and silt will return to the sea.

In case a mixture of marine clay, old alluvial stiff clay and clayey sand are dredged and pumped up into an enclosed pond, sand in the clayey sand and in the marine clay will settle near the outlet of the pipe line together with lumps of the stiff clay. On the other hand, fine particles of the clayey sand and marine clay will settle near the overflow weir. In this way, the reclaimed area will be formed in two parts–a sound part and a swampy part as shown in Fig. 5-1-1.
The percentage of the sound part to the whole reclaimed area is dependent on the percentage of each dredged material.

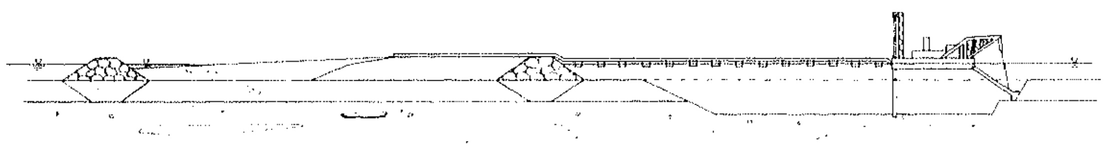
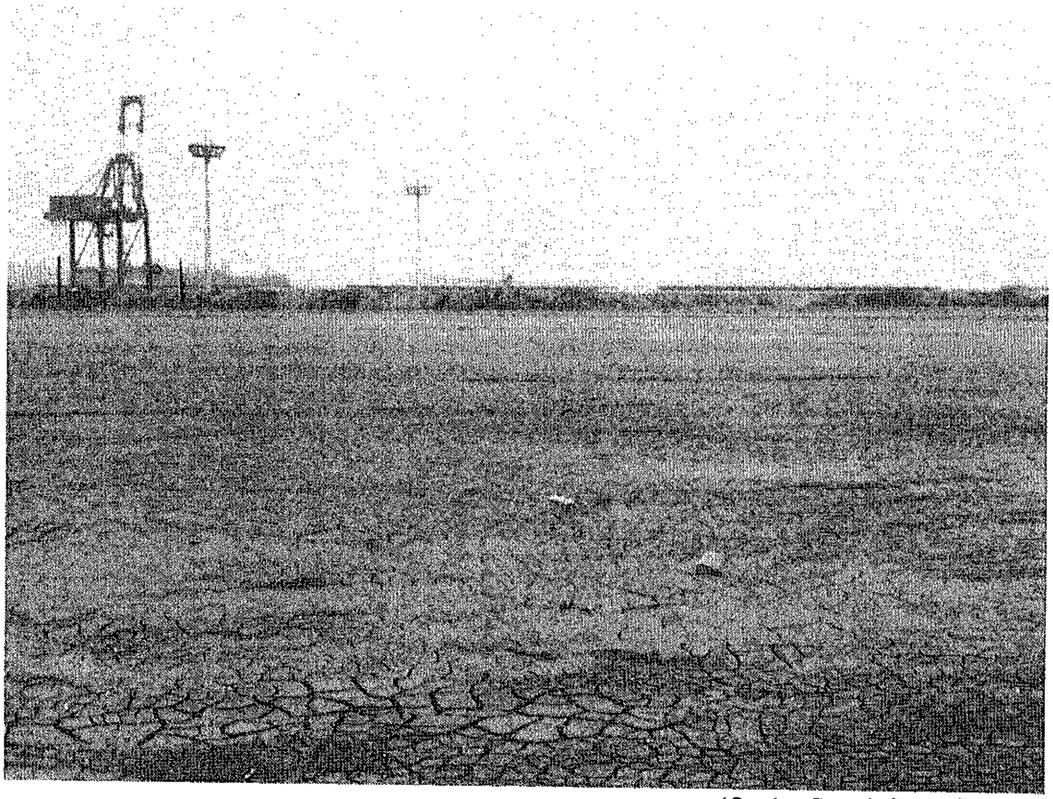


Fig. 5-1-1 Reclamation with Sand and Clayey Soil

The sound part of the land will not need to be discussed here. There may be a problem of settlement due to consolidation where marine clay exists below fill materials.

In the swampy area consisting of fine particles, the soil will have a water content of 100% to 400%. In Fukuyama reclamation project, which is presented in Chapter 6, the water content near the surface of the clayey fill was 300% one month after the filling was completed. It decreased to 200% half a year after the filling and 100 ~ 150% a year after the filling.

In Japan it is usually two years after the filling is completed when the surface of the swampy ground gets dried with numerous cracks and becomes sound enough for a man to walk upon, since the rate of desiccation is usually very small in winter time. In the process of the desiccation, the ground level will sink about 50 cm or so due to the shrinkage of the surface layer and natural consolidation of the clayey soil. This will have to be taken into consideration in deciding the top elevation of the filling.



(Osaka South Port, Japan)

The ground surface of a hydraulically reclaimed land with clayey materials has no trafficability for vehicles even if the surface has got dried. On such a ground a layer of sandy soil such as hill-cut soil has to be placed. In Japan, such surfacing soil is often placed with the help of a surfacing technique such as "rope-net method" before the surface becomes sufficiently hard. Such techniques will be described in Appendix B.
Fortunately Singapore is rich in strong sun shine, high temperature, and wind, and so the ground will get dried rapidly. It seems that such special techniques will not be necessary.

In Japan there are many examples that a reclaimed land filled with clayey material on an original sea bottom consisting of marine clay has been successfully utilized through various means of improvement (see Table 6-1-1).

A reclaimed land filled with marine clay has a problem of the settlement due to consolidation.

The amount of settlement depends on the nature of the original sea bottom soil, that of the fill material, the thickness of the fill and the surfacing soil, and the drainage condition in the process of the consolidation.

In Singapore, the sea bottom where a reclamation is likely to be planned is considered to be of marine clay.
When marine clay fill is placed on its top, the drainage condition of the pore water in the clayey fill is considered to be of one way, i.e. only upwards. When such fill is surfaced with a thin hill-cut soil, the ground is left under the state of natural consolidation and the settlement will last for a long time. In nearly one year the surface of the clayey fill will get dried and will settle 50 cm or so. After that, the rate of settlement will be rather great for the first one or two years and then will gradually decrease until it becomes slow and constant.

The shear strength or cohesion of the soft layer increases through the consolidation. The increment of the shear strength is

$$\Delta C = (0.2 \sim 0.3)\ \Delta P$$

Where, $\Delta C$ : increment of shear strength (at 100% consolidation)

$\Delta P$ : increment of load

If a fill material consisting of soft marine clay is left without placing surfacing soil, the surface of the soft fill will harden with cracks due to desiccation, but the cohesion of the subsurface clay will not greatly increase.
If it is left in this way until its natural consolidation is complete, the final cohesion C is

$$C = (0.1 \sim 0.15)z \qquad (z : \text{depth from the surface})$$

In general, the amount and rate of settlement due to consolidation and increase of cohesion can be estimated from the parameters of consolidation of the original sea bottom soil of the reclamation site and the dredging area, although they are dependent on the factors stated before.

Since the surface of the marine clay fill has not, even dried, trafficability for vehicles, it is necessary to place on it a layer of hill-cut soil at least 50 cm thick. Once such a layer is placed it can be used with little inconvenience as a green zone or a park.
If thicker surfacing layer is placed, the land can be used for a road or other structures which carry small load.

In future when structures or sewage pipes are installed on the reclaimed land, there will be a problem of uneven settlement at a point where the ground condition changes or

where the intensity of load changes, e.g. at the transition point from an embankment part to an abutment supported on pile foundation.
In case of sewage the uneven settlement sometimes causes reversion of the gradient of the pipeline, when this problem is neglected.
There will be another problem of negative friction of pile foundation installed in consolidating ground.

The solutions to these problems will be discussed in the following section.

## 5-2 Solutions to the Problems

The biggest problem of the reclaimed land with clayey fill is settlement of the ground due to consolidation.

If a rather light structure is built on such soft ground, this problem can easily be dealt with by a comparatively simple improvement.
When a heavy structure such as multi-storied apartment building is built, a conventional pile foundation will have to be used, in which case negative friction on the piles must be taken into account.
There are various methods on this matter.
The most commonly used method is to increase the bearing capacity of each pile or to apply coating such as asphalt to the piles.

For the uneven settlement between a pile-supported part and an unsupported part, raising the elevation of the unsupported part for an expected settlement or partial soil improvement, which will be described below, is the most commonly used method. In case of gutter, sewage pipeline, or road, it is advisable that such structure be constructed as a temporary one at first. The permanent structure can be built when the rate of settlement has decreased.

In Japan, where many reclaimed lands filled with soft marine clay on top of the original sea bed of marine clay have been created, many techniques or methods to improve soft subsoil of such lands have been developed and utilized.
They will be classified into five groups as follows.

- Subsoil Improvement
  - Preloading
  - Drainage
    - Sand Drain
    - Paper Drain (cardboard drain)
    - Bagged Sand Drain
  - Sand Compaction Piling
  - Solidifying
    - Solidifying by Cement
    - Solidifying by Lime
  - Dynamic Consolidation

Sand compaction piling is a kind of replacement method, in which a large amount of sand is squeezed into soft subsoil forming a series of compacted sand piles by means of a casing and a vibrohammer or other equipment.
Since a large amount of sand is required in this method, it is not suitable for the area where sand is scarce.

In the solidifying method, cement or lime is grouted into a soft layer to improve and mix with the clayey soil, forming solidified soil.
Since this method is very costly, its application is usually limited to a rather small area, such as the foundation of a gravity-type quaywall.

Dynamic consolidation is a method to compact ground by dropping an extremely heavy ram from a great height.
It is said that this method is also effective to a ground consisting of a clayey soil.
But the improving mechanism on the clayey soil is not yet established.

The three methods abovementioned will not be discussed in details here.

The most commonly used and the seemingly most effective subsoil improvement techniques will be preloading and drainage. These two methods will be briefly described in 5-2-1 and 5-2-2.

## 5-2-1 Preloading

This is a traditional subsoil improvement technique. The purpose is to force soft ground to settle in advance, prevent prolonging settlement in future, increase the shearing strength of the subsoil, and hence consolidate the soft ground.

As shown in Fig. 5-2-1, a load of earth fill is placed as a surcharge on top of the soft ground.

The surcharge creates an excess pore water pressure in the clayey soil and the pore water is squeezed out of the soil towards the surface and, if there is a pervious sand or gravel layer below the clayey soil, towards the pervious layer.

The amount of surcharge is decided considering the required strength of the subsoil and permissible settlement after the improvement.

If the ground is extremely soft, the surcharge must be placed in two or more stages as shown in Fig. 5-2-1.

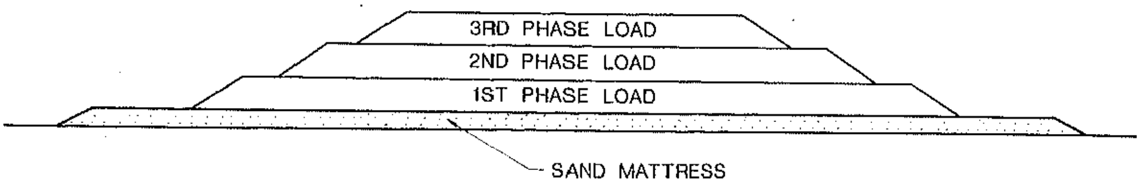



Fig. 5-2-1 Preloading

Atomospheric pressure is sometimes used as the surcharge. In this method the area to be improved is covered with an airtight membrane, of which ends are sealed into the sorrounding ground. A vacuum pump creates a vacuum beneath the membrane and the atmospheric pressure is applied on the area. Lowering ground water table by dewatering also causes an increases of the load on the soft subsoil. This can be classified in this category.

If a surcharge exceeding the load that the ground is expected to support in service is removed, settlement under the reduced loading can be made very small.

Where the thickness of the soft layer is rather small, the preloading alone will be sufficient. If the clayey layer to be improved is thick, the consolidation process is very slow.

To accelerate the consolidation process in this case, the following drainage methods are applied.

2 Drainage method

The basic idea of the drainage method is to provide vertical drains in the soft soil to be improved. This is usually used in combination with the surcharge. By this method, th pore water which is squeezed out of the soil flows horizontally to the nearest drain mes up to the surface through them. The time required for the consolidation y on the spacing of the drains and also on the thickness or size of the dr

se of the vertical drains shortens the consolidation p or several months. There are many kinds of methods and drain materials. Most commonly used are sand drains, paper (cardboard) drains and bagged sand drains.

– Sand drain method

This is a conventional and the most commonly used method, in which sand piles are used as the vertical drains.
Sand piles are installed usually by driving a casing pipe with a vibro-hammer or a diesel hammer. They are sometimes installed with an auger boring machine or with water jet. The selection of the equipment depends on the soil condition. The maximum length of a sand pile which can be installed is about 30 meters in the driving system. In the auger method it is usually 15 meters, while it is 20 meters in water jet method.

Where the clayey layer to be improved is extremely soft, it becomes sometimes impossible to maintain the continuity of a sand pile. In such a case the following paper drain or bagged sand drain will be the solution.

– Paper drain (cardboard drain) method

In paper drain method, a strip of paper (cardboard wick) is used instead of a sand pile. Fig. 5-2-2 shows the cross-section of a cardboard wick which has been commonly used in Japan. It has a cross-section 10 cm wide and 3 mm thick and has ten small channels, which provide the passage for water.
These days a plastic board of an approximately same cross-sectional area is frequently used instead of a cardboard (see Fig. 5-2-3).

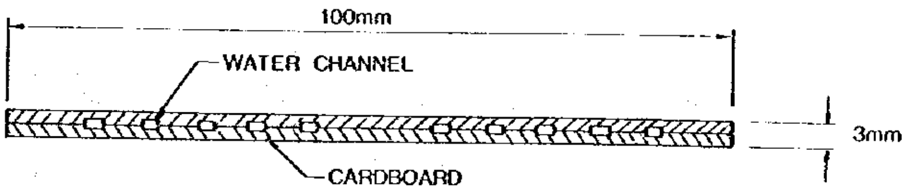



Fig. 5-2-2 Cardboard Wick

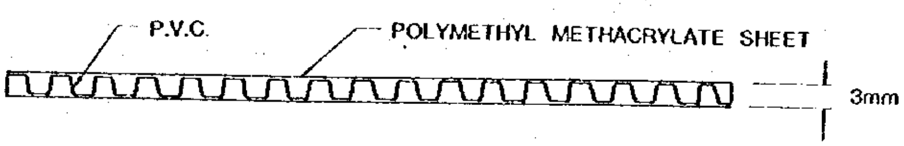



Fig. 5-2-3 Plastic Drain Board

A paper drain (or a plastic drain) is usually driven into the ground in a casing (or a mandrel) by mechnical means. Fig. 5-2-4 shows the driving procedure.
A paper drain driving machine is capable of driving a drain of 25 m.

The design of the paper drain is made in the same way as the sand drain, i.e. a paper drain is equivalent to a sand drain of 5 cm diameter. Therefore, in the paper drain method more drains are required than in the sand drain. But since installing speed is much faster in the paper drain, the total period required for installing paper drains is shorter than that required for installing the sand drains with the same effect.

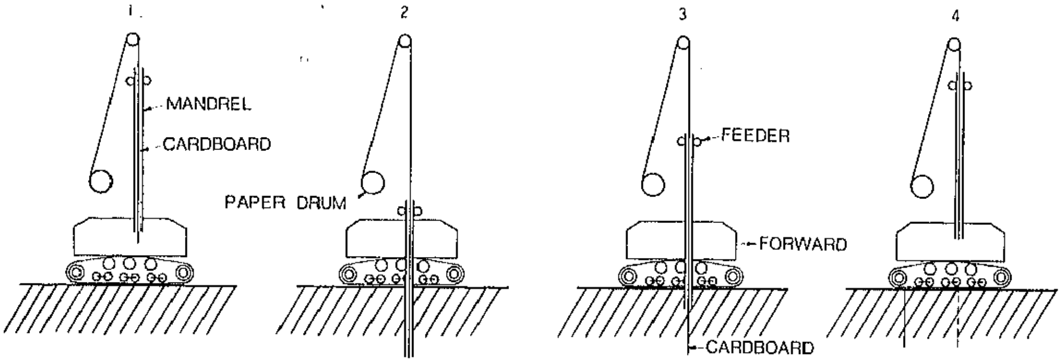


Fig. 5-2-4 Driving Procedure of Paper Drains

– Bagged sand drain method

This is a variation of the sand drain method. A bagged sand drain is formed by stuffing sand into a long bag of permeable and corrosion-resisting plastic woven fabric having a high tensile strength. It is capable of maintaining its uniform diameter and its continuity. A bagged sand drain can be of much smaller diameter than a sand drain, which is usually 40 cm in diameter or more. In Japan a bagged sand drain having a diameter of 12 cm is commonly used.

By installing bagged sand drains of a small diameter at a smaller spacing, the period of consolidation can be greatly shortened. Fig. 5-2-5 shows a procedure to install a bagged sand drain.

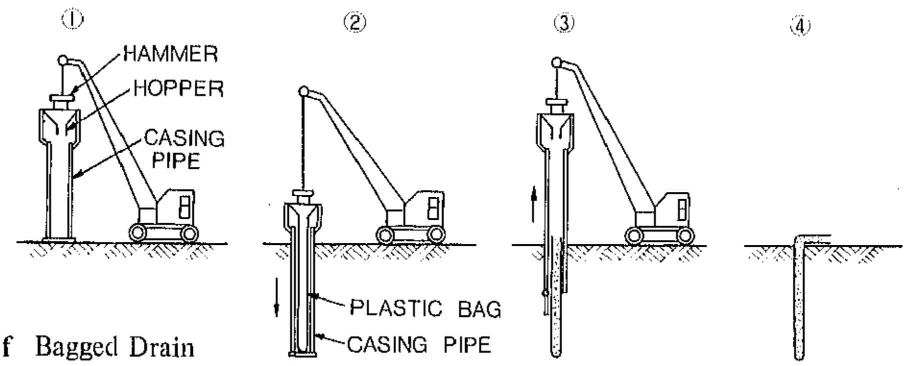
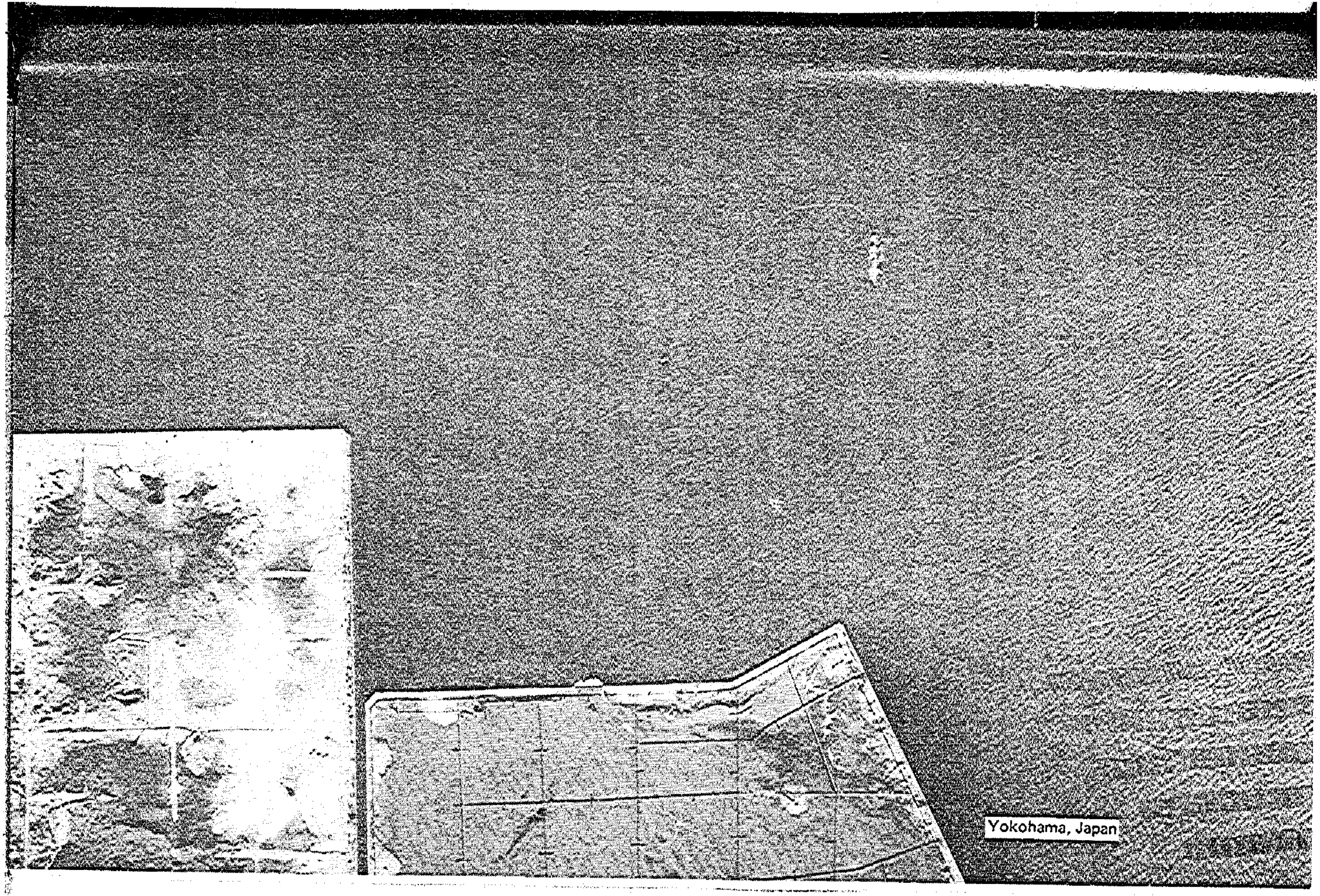



Fig. 5-2-5
Installing Procedure of Bagged Drain


Yokohama, Japan

## [6] EXAMPLES OF RECLAMATION PROJECTS USING SOFT SEA BOTTOM MATERIAL IN JAPAN

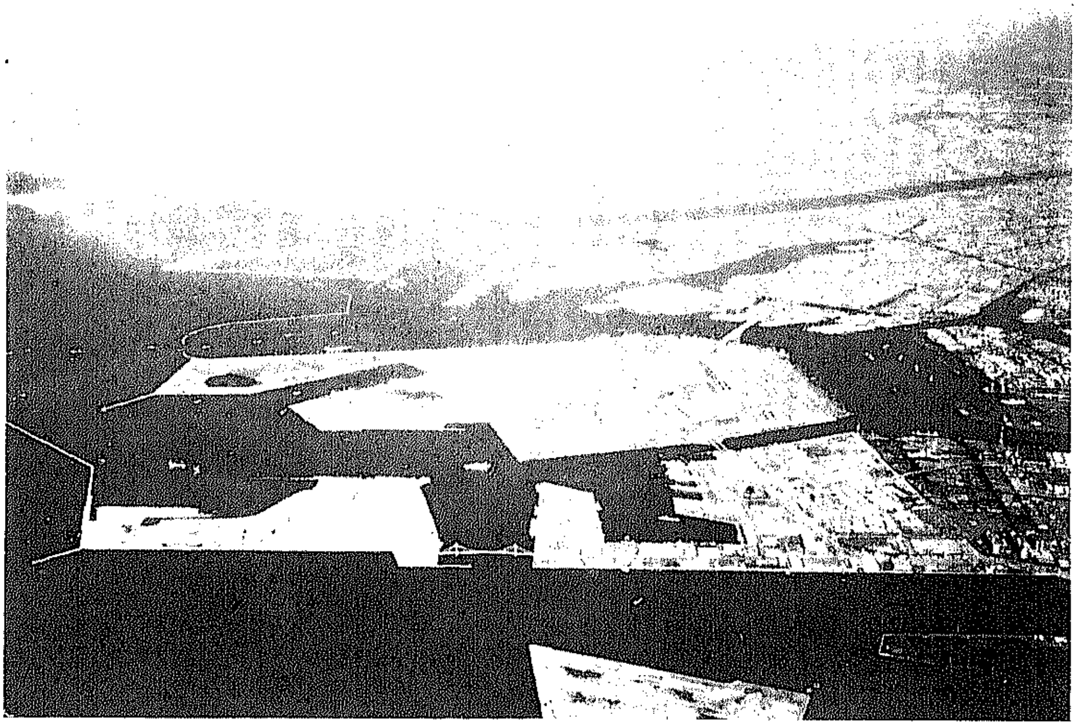
In Japan, many reclamation projects have been carried out using soft sea bottom soils as fill material. Some of them are listed below in Table 6-1-1.

Table 6-1-1 Reclamation Projects in Japan using Soft Sea Bottom Soils

| Location | Area Reclaimed | Purpose of Usage | Main Fill Material |
|---|---|---|---|
| Hiroshima City Hiroshima Pref. | 128 ha | Car Factory | Silty Clay |
| Fukuyama City, Hiroshima Pref. | 735 ha | Steel Mill | Clayey Silt |
| Mizushima City, Okayama Pref. | 413 ha | Oil Refinery, etc. | Clay and Gravel |
| Amagasaki City, Hyogo Pref. | 12 ha | Tank Farm, etc. | Clay |
| Osaka City, Osaka Pref. | 930 ha | Housing, Harbour, etc. | Clay and Sand |
| Sakai City, Osaka Pref. | 440 ha | Heavy Industry, Harbour, etc. | Gravel and Clay |
| Yokkaichi City, Mie Pref. | 68 ha | Power Station, etc. | Sand and Clay |
| Nagoya City, Aichi Pref. | 337 ha | Steel Mill | Silt and Silty Sand |
| Nagoya City, Aichi Pref. | 480 ha | Power Station | Sand and Silty Sand |
| Handa City, Aichi Pref. | 111 ha | Power Station | Sand and Clay |
| Kawasaki City, Kanagawa Pref. | 67 ha | Industrial Estate | Clayey Sand |

In many other projects, soft sea bottom soils have been utilized. In this Chapter two major reclamation projects, one in Osaka and the other in Fukuyama, are introduced as typical projects.

## 6-1 Reclamation Project at Osaka South Port



An area within the radius of 50 kilometers from centering Osaka City is called 'the Greater Osaka Region', which has a population of 14 million and 40% of the whole national export trade is concentrated there.

A plan on reclamation of huge industrial estate offshore the southern Osaka, the center of the Region, was drawn and the work was started in 1958.
The total area to be reclaimed was planned to be about 574 ha at the initial stage, but later it has become to the present square of about 930 ha after the several changes corresponding to the progress of economic circumstances.

Up to March 1979, about 80% of the reclamation work has been completed and the whole work is scheduled to be completed around March, 1981.
Fig. 6-1-1 is a plan of the entire schedule.

| ZONE | AREA | % |
|---|---|---|
| WHARF ZONE | 141.4 | 15.2 |
| WHARF OPERATION RELATED AREA | 350.3 | 37.7 |
| RESIDENTIAL ZONE | 62.1 | 6.7 |
| PARKS & GREEN BELTS | 78.1 | 8.4 |
| OFFICE & COMMERCIAL ZONE | 53.6 | 5.8 |
| URBAN INDUSTRIAL ZONE | 94.3 | 10.1 |
| RESERVED SPACE FOR ROADS, ETC | 150.1 | 16.1 |
| TOTAL | 929.6 | 100 |

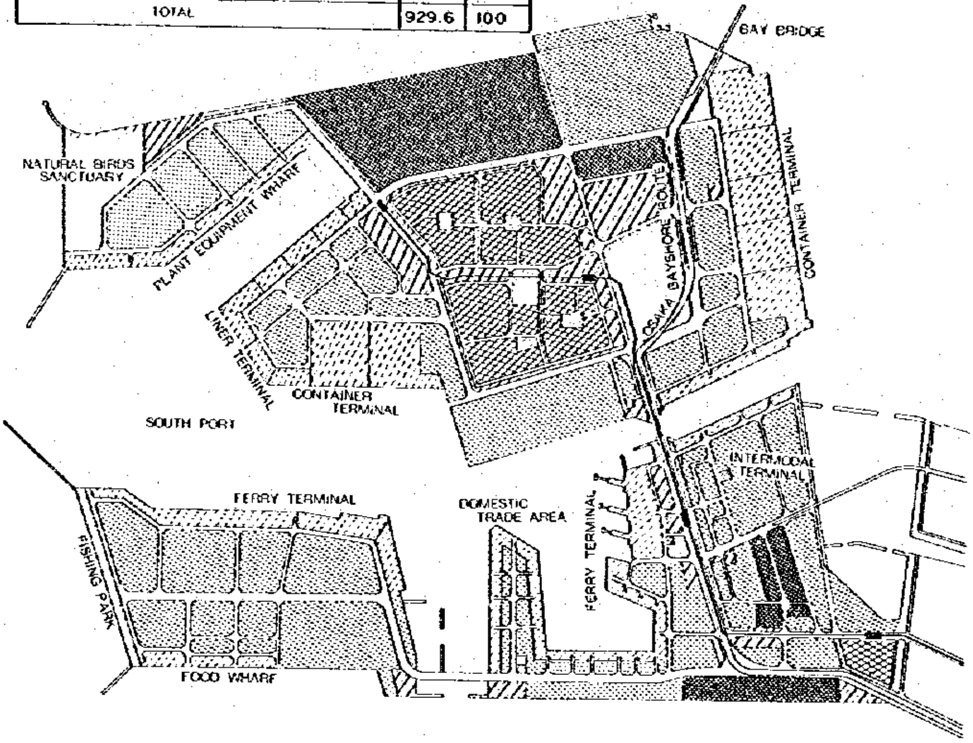



Fig. 6-1-1

## 6-1-1 Nature of sea bottom soil at the reclamation site

The soil profile of the original sea bottom at the reclamation site at Osaka South Port is shown in Fig. 6-1-2.

Summarizing the geology in the port area, there appears the top layer of Old Alluvial soil which is deemed as a burried terrace deposit at −22 m to −25 m D.L. in the area along Yamato River, southern boundary of Osaka. In other area a deeply undulating gravel stratum which is the top layer of the Old Alluvium (called Tenma Layer) having a thickness of about 5 m and N-value of over 50.

These layers are considered as the bearing strata of most structures and buildings to be erected in this area.

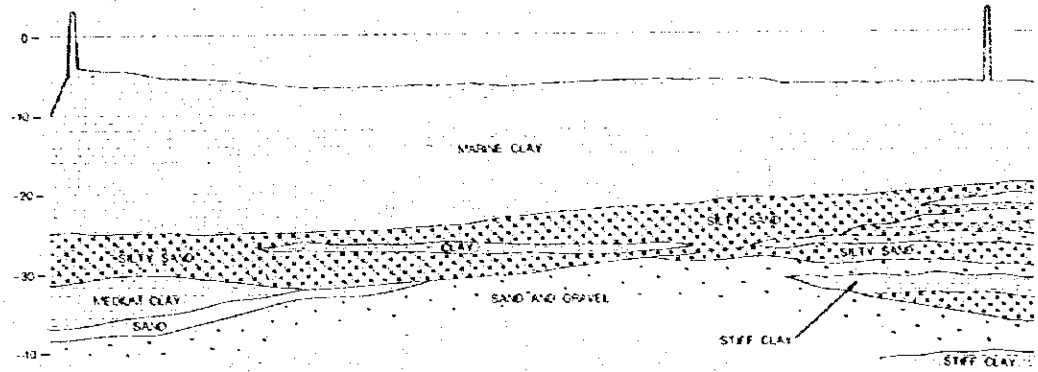



Fig. 6-1-2 Soil Profile before Reclamation

Alluvium deposited over these strata is divided into upper alluvium and lower alluvium. Lower alluvium deposits around –25 m to –22 m D.L. having a higher sand content.
Upper alluvium is silty clay, being placed thereon, comperatively homogenous but very soft and is over 15 m in thickness.
Typical borehole log, grain size distribution, moisture content, consistency, dry/wet unit weight, void ratio, unconfined compression strength before reclamation in Osaka South Port are shown on Fig. 6-1-3.

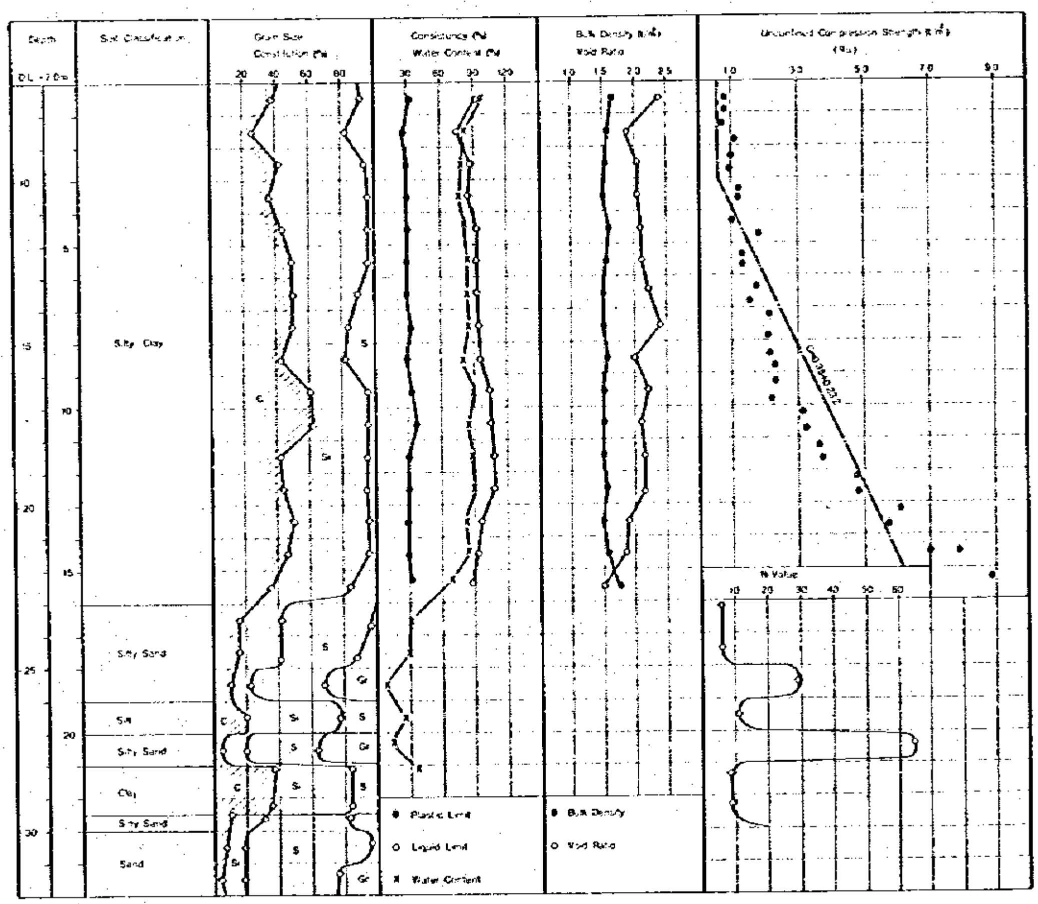


Fig. 6-1-3 Typical Borehole Log & Soil Properties

Nature of average ground of upper alluvium as a most important factor for reclamation is as follows:--

| | |
|---|---|
| Clay content : | 40 ~ 60% |
| Moisture content : | 80% |
| Liquid limit : | 100 ~ 110% |
| Void ratio : | 2.0 ~ 2.5 (average 2.2) |
| Unconfined compression strength : | Upper layer 1.0 ~ 1.5 t/m² <br> Middle layer 1.5 ~ 2.5 t/m² <br> Lower layer 3.0 ~ 8.0 t/m² |

6-1-2 Outline of reclamation project in Osaka South Port

Reclaimed area at Osaka South Port consists of Zone 1, Zone 2, Zone 3, Zone 3', South Quay, Middle Quay, and North Quay (see Fig. 6-1-4). South Quay, Middle Quay, and Zone 3 have been reclaimed with only marine sand and hill-cut soil.
Zone 1, Zone 2, Zone 3 and North Quay have been filled with silty clay obtained by hydraulic cutter suction dredgers from the anchorages and navigation channels near the reclamation site and then after drying, sand or hill-cut soil has been deposited thereover. 30% of reclamation in area has been carried out with marine sand and hill-cut soil and remaining 70% with the dredged silty clay.

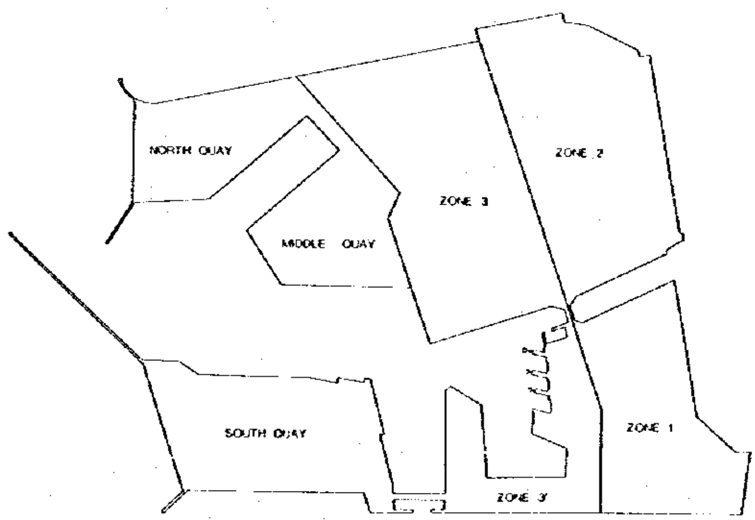


Fig. 6-1-4

For reclamation sites with marine sand and hill-cut soil, first of all, sand drain piles have been driven over the whole areas prior to the filling.
In order that sand drain for future drainage of pore water in the process of consolidation might not be cut due to ground failure or plastic flow of clay, marine sand has been placed in many stages by sand placing barges.

These procedures have been taken up to +2.0 m D.L., followed by placing hill-cut soil with thickness of 6 m as surface soil.

For the reclamation sites with clayed material, after the whole areas have been enclosed beforehand by revetments (partly temporary ones) and overflow weirs installed, then hydraulic cutter suction dredgers have started discharging the sea bottom clay directly to the filling areas.

In the course of this reclamation operation, there was a phenomenon that as mentioned in Chapter 5 comparatively coarse soil, in general deposits near and around the outlet of the discharge pipeline and fine soil deposits around overflow weir far therefrom.

Since most of the periphery line of the reclaimed land was to be utilized as a quaywall, quawall structures were constructed beforehand as the revetment for the reclamation.
The quaywall structures were of replacement type. It facilitated a speedy filling with more safety.
Two of the cross-sections of the quaywall structures are shown in Fig. 6-1-5 and Fig. 6-1-6.

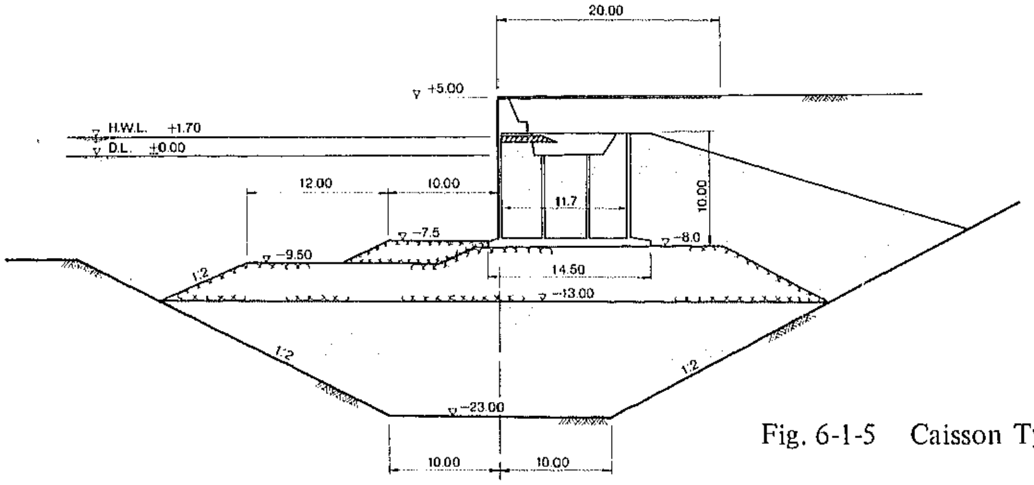



Fig. 6-1-5 Caisson Type Quaywall

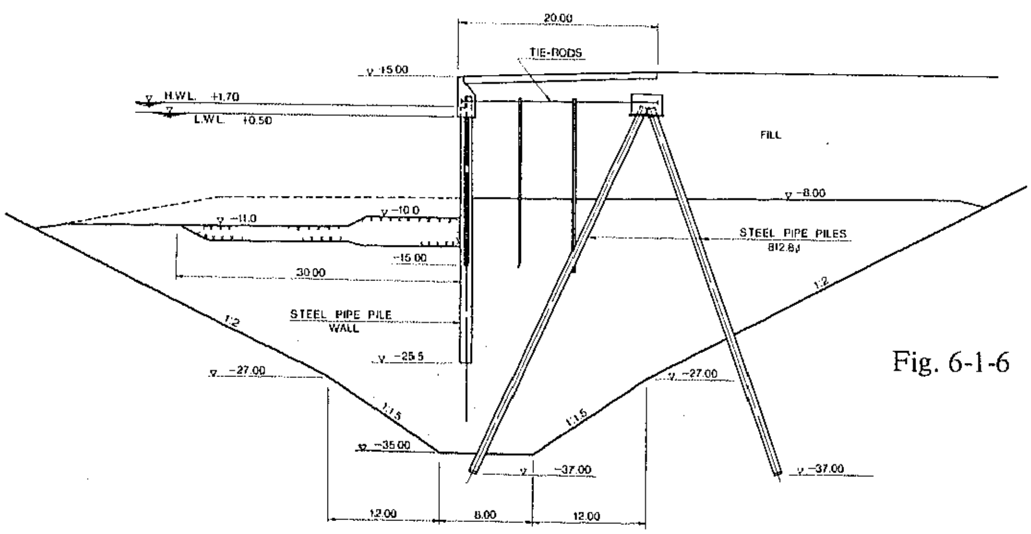



Fig. 6-1-6 Steel Pipe Pile Quaywall

## 6-1-3 Subsoil improvement

–Area filled with marine sand and hill-cut soil

Prior to the filling work sand drains of 40 cm diameter were driven at a spacing of 3 meters over the whole area to be reclaimed.
One of its purposes is to prevent a prolonging settlement due to consolidation under the weight of the fill material. Another is that if the sand drains are driven after the filling, they must be driven through a thick layer of sand and hill-cut soil fill, which is uneconomical.

–Area filled with silty clay

After the areas filled with silty clay were left as they were to get dried for about two years and then covered with surfacing soil, subsurface soil improving works were carried out. Applied here were improvement works by sand drains, paper drains, plastic drains, bagged sand drains, deep wells, and so forth. Subsoil improvement was not applied on the area allocated for parks or green zones.

The best result has been obtained from the improvement work done in the Port Town area in Zone 3 where the plan of land use has been decided early.
The method is the combination of the sand drain, bagged drain and the deep well.
The work was carried out in the following procedure (see Fig. 6-1-7).

(1) Placement of a sand mattress 1.2 meters thick over the seabed.
(2) Installation of sand drains by a floating sand pile driver.
(3) Installation of deep well.
(4) Completion of revetment.
(5) Hydraulic filling by dredgers.
(6) Drying period (approx. 2 years).
(7) Placing of surfacing soil.
(8) Installation of bagged sand drains.
(9) Lowering of water table by operating a vacuum pump and a water pump.
(10) Placing of additional soil.

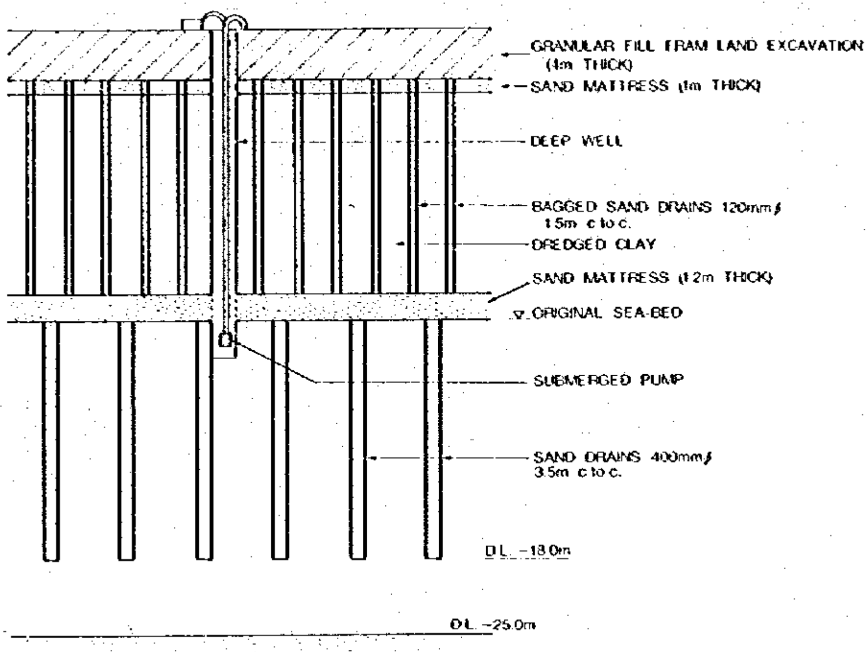



Fig. 6-1-7 Subsoil Improvement by Sand Drains,Bagged Sand Drain and Deep well

The pumping operation has been conducted by repeating the following procedure.

(1) A vacuum pump creates a vacuum in the well and lowers the water table.
(2) Pore water is squeezed out into the drains and then into the well through the sand mattresses.
(3) When the water table rises to a certain level, water pump starts to operate.

Fig. 6-1-8 shows the theoretical diagram of this method. The intensity of the load increases as the water table is lowered. When the water table is lowered to the level of the lower sand mattress, the increment of the effective stress shown in Fig. 6-1-8 is obtained.
When consolidation is completed and the pump has ceased to operate, the water table recovers and the said increment becomes zero.
Since the increment is deemed to be an excess surcharge, the clayey layer below the lower sand mattress has been theoretically overconsolidated and hence no settlement later on. In reality, however, there will be some residual settlement due to the creep of the clay. But there are no effective measures to prevent it.
Since the method introduced above requires no fill material for loading, the time and cost for removing the load can be saved. Further the mechanism of the method is simple and there are few uncertain factors.
It has been proved in this project that if applied under proper execution control, this method is highly reliable for the improvement effect.

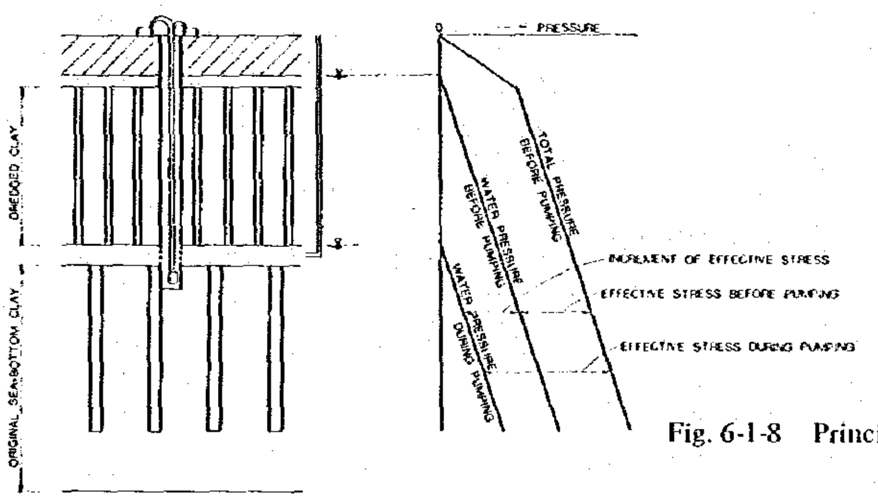


Fig. 6-1-8 Principle of the Method

## 6-2 Land Reclamation for Seaside Industrial Area at Fukuyama City

A large-scale of reclamation scheme was planned for construction of a new steel mill for Nippon Kokan Kabushiki Kaisha (NKK) at an area adjacent to Fukuyama port located in the east end of Hiroshima Pref. Reclamation of the land, of total square to the extent of 735 ha, was carried out mostly by hydraulic dredgers discharging the sea bottom material around the reclamation area,except for a small area where hill-cut soil were used. The work was commenced in March, 1962, and completed in four-and-a-half years time with a total cost of approx. 15 billion Japanese Yen.

### 6-2-1 Quality of the seabed soil beneath the proposed land

Fig. 6-2-1 presents the soil profile of the seabed around the proposed reclamation area, which shows that the seabed level changes relatively moderately with the depth of −1.00 m at the shallowest point and −4.00 m at the deepest point. The top layer about 10 m in thickness is soft silt of alluvium, underlain by hard clay of old alluvium 1 ∿ 5 m in thickness.

Beneath these two layers successively exist sand or sand with gravel layers of a very high bearing capacity, which is quite suitable as the bearing stratum for foundations of the mill, and in some parts hard sandy silt layer exists in between the sand or sand and gravel layers.

Fig. 6-2-2 shows the relation of unconfined compression strengths and depths of the undisturbed samples collected from the silt layer. Result of particle size analyses tells, as shown in Fig. 6-2-3, that the alluvium consists mostly of silty soil as in the Mississippi classification, and is judged to be an extremely soft silty layer in consideration of the result as well as the strength of the sample.

Table 6-2-1 shows the results of physical tests and Table 6-2-2 shows the parameters of consolidation obtained from consolidation tests respectively.

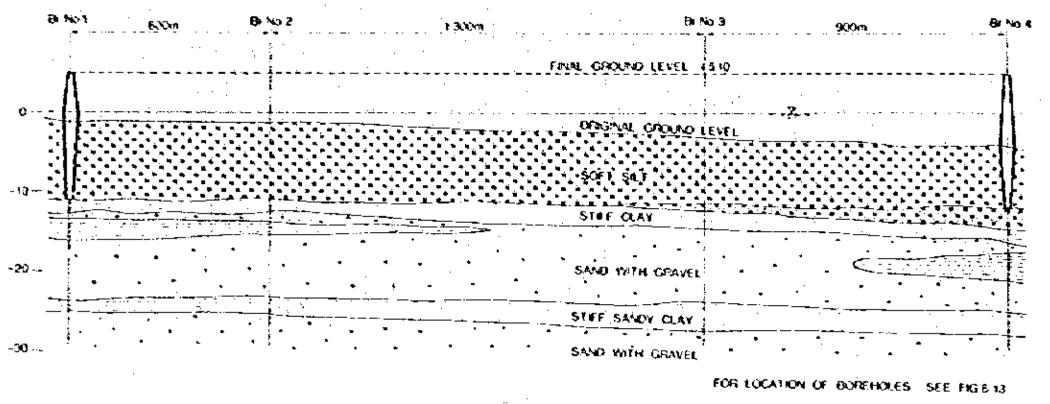



Fig. 6-2-1 Soil Profile

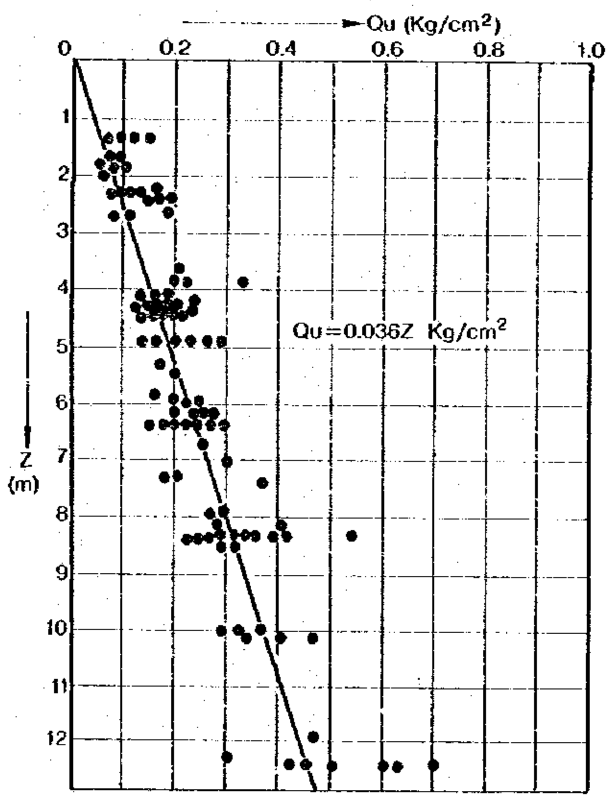



Fig. 6-2-2 Qu–Z

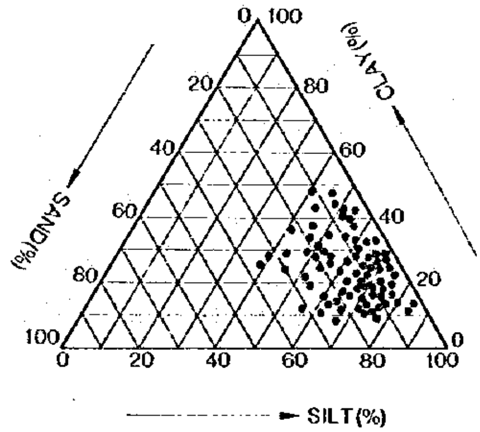



Fig. 6-2-3 Particle Size Distribution

Table 6-2-1 Physical Properties

| | | |
|---|---|---|
| Silt Content | | 40 ~ 80% |
| Specific Gravity | G | 2.46 ~ 2.79 |
| Bulk Density | $\gamma$ | 1.36 ~ 1.96 t/m$^3$ |
| Void Ratio | e | 1.5 ~ 4.0 |
| Water Content | $\omega$ | 35 ~ 140% |
| Liquid Limit | (L.L.) | 70 ~ 130% |
| Plastic Limit | (P.L.) | 20 ~ 50% |
| Plasticity Index | (P.I.) | 20 ~ 110% |

Table 6-2-2 Consolidation Tests Results

| | | |
|---|---|---|
| Coefficient of Consolidation | $C_v$ | $3.0 \times 10^{-2}$ cm$^2$/min. |
| Modulus of volume change | $m_v$ | $2.6 \times 10^{-1} \sim 2.3 \times 10^{-2}$ cm$^2$/kg |
| Coefficient of Permeability | $\kappa$ | $7.2 \times 10^{-5} \sim 2.7 \times 10^{-7}$ cm/min. |

### 6-2-2 Outline of the reclamation work

The reclamation required approximately 54 million cubic meters of fill material in net volume, for which the dredged material from the anchorage basins nearby was mainly used. Fig. 6-2-4 shows the dredging areas.

The silt and underlying hard clay and sand with gravel in the western, southern, and eastern basins were dredged by hydraulic cutter suction dredgers, while silt in the navigational channel was dredged by grab dredgers.

Breakdown of the fill materials is as follows:—

| | |
|---|---|
| Hard clay, sand with gravel of the sea bottom | 17.5 million cu.m. |
| Silt in channel | 7.0 |
| Hill-cut soil | 1.9 |
| Silt of the sea bottom | 27.6 |
| Total: | 54.0 million cu.m. |

According to the detailed layout of the mill, such areas planned for construction of blast furnaces, revolving furnaces or other heavy structures were reclaimed with sand with gravel and hard clay. The other areas were reclaimed with silt by switching the outlets of discharging pipelines except some parts that were reclaimed with hill-cut soil (See Fig. 6-2-5).

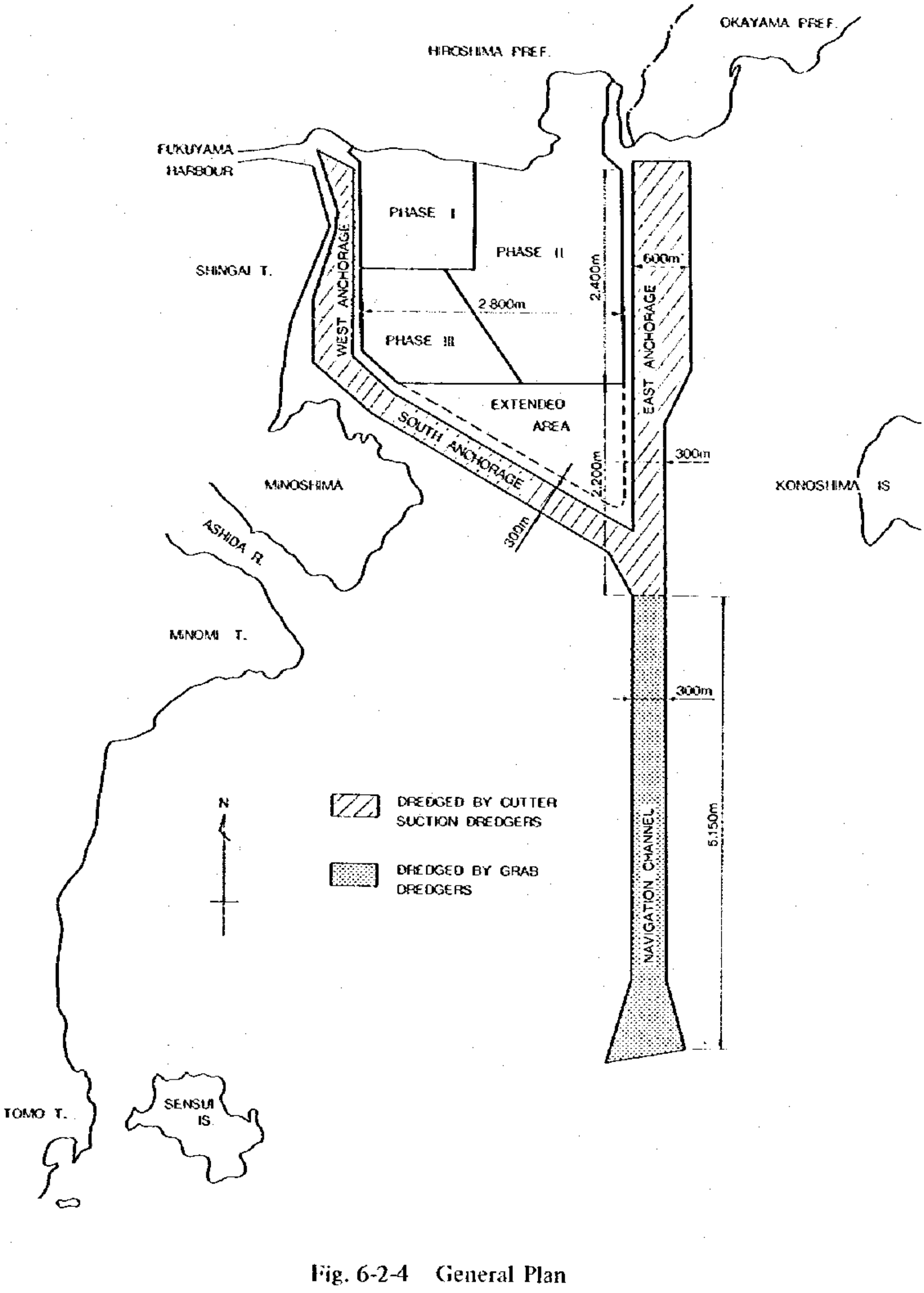



Fig. 6-2-4 General Plan

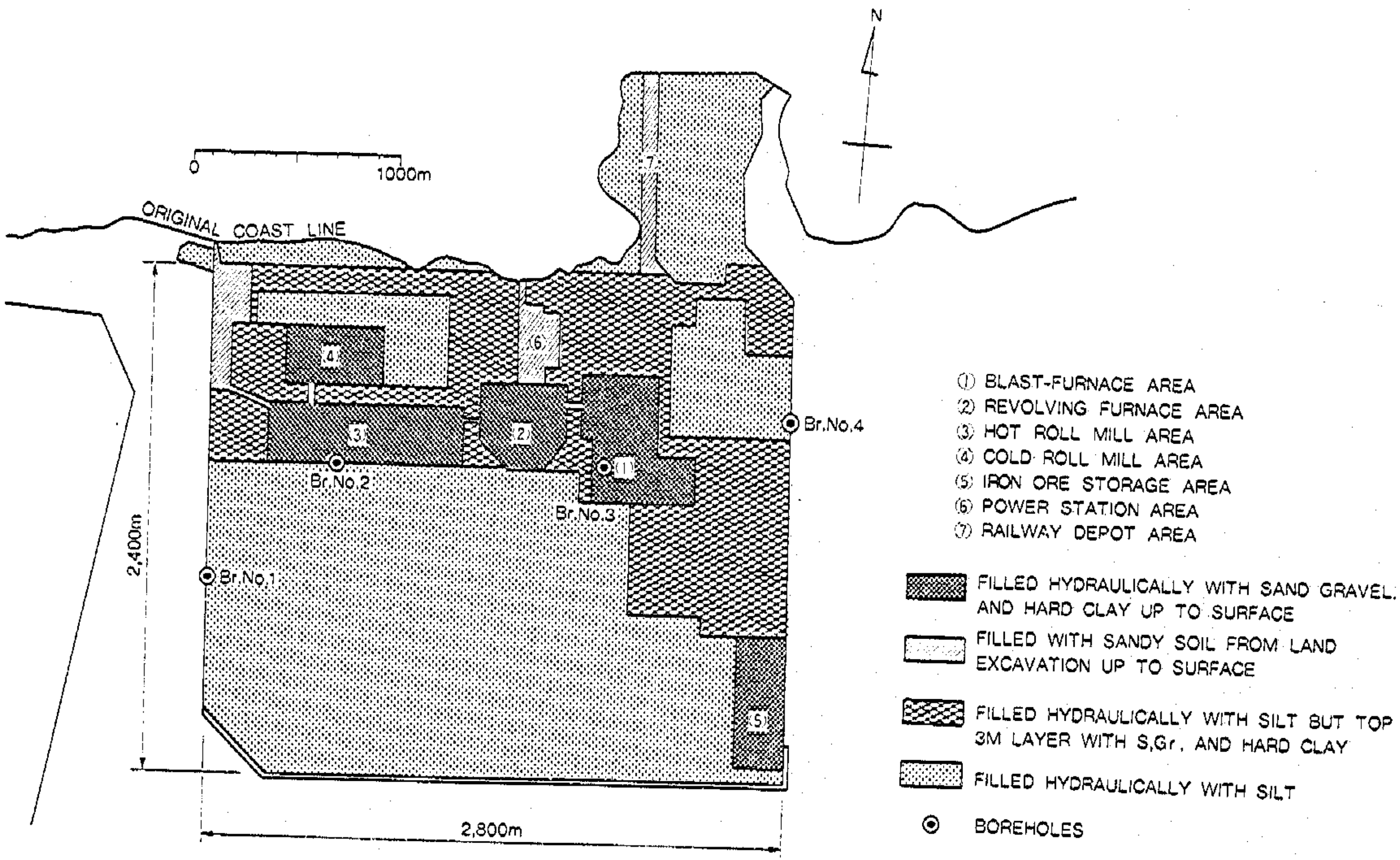



Fig. 6-2-5 Fill Material Allocation Plan

Before commencement of dredging, the eastern and the western revetments were constructed, starting from the north side, as temporary ones, since they were planned to be replaced with the permanent quay walls. The permanent revetment of a strong cross-section was constructed at the south side which was to resist strong waves in stormy weather.

Fig. 6-2-6 and 6-2-7 show the cross-sections of the revetments.

As the reclaimed area was to be handed over in three phases, the reclamation was commenced in the order of Phase I, II, and III as shown in Fig. 6-2-4 according to the constructions plan of the mill, after completion of the said revetments and temporary partition enbankments dividing each part within the reclamation area. Main equipment for reclamation work was the hydraulic dredgers of 4,000 HP gas turbine with a maximum dredging depth of −21 m. At the peak of the work there were employed over 10 numbers of the hydraulic dredgers including 5 of the above type.

Silt excavated by the grab dredgers in the proposed channel was transported by the hopper barges through an opening in the revetment, and was dumped within the silt-reclamation area. Since a large volume of soils was discharged by relatively large-sized dredgers for those days, plastic flows and small-scale circular failures occurred on some parts of the original sea-bed, but as a whole the work was carried out smoothly and successfully as scheduled.

An additional land reclamation was carried out from 1969 to 1972 at the southern end of the original reclamation site, adding an area of about 137 ha as shown in Fig. 6-2-4.

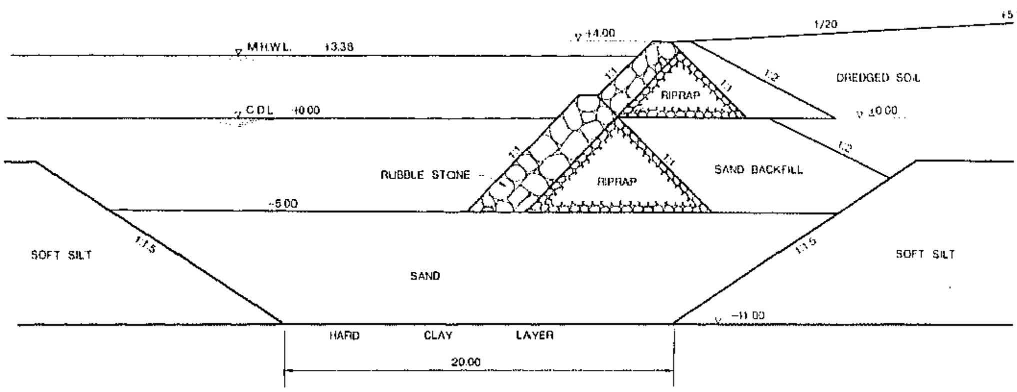



Fig. 6-2-6 East and West Revetment