Securing disposal fields to receive soft dredged material has become a big challenge, particularly in Japan where finding disposal fields is getting more difficult. Research to utilise soft dredged material for construction as recycled material is quite advanced in Japan. The PM-CLAY (pre-mixed clay) Method is a solidification method for soft sediment developed within this social background.

A large-scale perimeter bund was recently constructed in Asia using the PM-CLAY Method. For this project, an unprecedented volume of 3,000,000 m³ pre-mixed clay (hereafter, “PM-CLAY”) was placed at a level 30 m below sea level. This method uses PM-CLAY (a mixture consisting of natural clay, water and cement) as a construction material, which is useful for reclamation, revetment and perimeter bunds. The PM-CLAY Method has many special features. Especially, it can produce a variety of desired materials to cope with each particular construction purpose by adjusting the water and cement balance according to the characteristics of the natural clay. As PM-CLAY consists of fluid materials, it can be used without additional soil improvement works.

In this project the perimeter bund was constructed with an inclined face of eighteen (18) degrees (1:3) by direct placing PM-CLAY without using any mold. The PM-CLAY Method also helped reduce the local procurement of construction materials at the site area as it uses PM-CLAY that is a mixture of natural clay, water and cement.

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CONSTRUCTION OF A PERIMETER BUND USING THE PRE-MIXED (PM)-CLAY METHOD

A large volume of soft dredged material may be obtained from dredging works such as harbour dredging. In the past such material has been disposed of in gravel disposal fields or used to fill in the ground because soft dredged material cannot be used directly as a construction material. In recent years, however, securing disposal fields to receive soft dredged material has become a big challenge, particularly in Japan where finding disposal fields is getting more difficult. In addition, research to utilise soft dredged material for construction as recycled material is quite advanced in Japan, since obtaining beach sand or pit sand that can become high-quality construction material is growing more difficult.

The PM-CLAY (pre-mixed clay) Method is a solidification method for soft sediment developed within this social background. The PM-CLAY Method has been applied in many construction works accumulating experience and extending the areas of application in Japan, but it has rarely been applied in any overseas large-scale marine construction. This report describes the outline of the PM-CLAY Method and an example of its application in large-scale perimeter bund construction work overseas.

THE PRE-MIXED-CLAY METHOD

The PM-CLAY Method is an engineering method to produce solidified disposed soil with
FEATURES OF THE PM-CLAY METHOD

The features of the PM-CLAY Method are summarised as follows:

- The method can solidify a large volume of cohesive soil.
- To cope with large-scale harbor construction work, the PM-CLAY vessel has nominal capacity to place solidified soil at a rate from 300 to 500 m³/hr.
- The method produces a flowing and pumpable feed material where tamping is not required.
- The PM-CLAY Method has a feature that allows the processed soil to flow and makes construction with pump feeding possible without the need of tamping since it uses cohesive soil as raw material.
- Also, since it uses cohesive soil as raw material, the artificial ground is lighter compared to that made of general ground material.
- PM-CLAY soil is lighter compared to solidified soil made from sandy soil.
- The process is applicable in a relatively narrow space. The PM-CLAY Method makes it possible to operate in a narrow work space, because there is a series of work stations; soil-gathering, production of processed soil, and placement is performed in a specialised vessel.
- Solidity and the ability of the solidified soil to flow are easily adjustable. By adjusting the amount of additional water or solidification material according to the result of the prior combination tests, solidified soil with solidity or flow ability optimal for the purpose of use can be produced.

EXAMPLES OF PM-CLAY METHOD APPLICATION

Some major applications and their effects are shown in Table I. Many of the past results relate to the application being used for landfill material for marine and inland reclaimed land, embankment levees, widening material and divider material. It can also be used as backfill material for quays and revetments because of the benefits from earth load reduction, prevention of liquefaction and achieving desired solidity.

![Figure 1. Construction method of the PM-CLAY Method.](image-url)
Table I. Typical application examples of the PM-CLAY Method and their effects.

<table>
<thead>
<tr>
<th>Application</th>
<th>Effect of the PM-CLAY Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine and inland landfill material</td>
<td>Effective use as recycled dredged material can reduce any environmental burden. Large volumes and rapid loading is possible as landfill material for large-scale filled-in ground, shortening the construction period and reducing the cost. The reclaimed land is easier to use with no need for soil improvement and no ground sinking because the material can be provided in a short period with desired solidity through the addition of solidification material. Since the material can be pumped via pipelines on the sea surface and placement underwater is also possible, land-filling can be started from any location. Also with additional strength it is easier to ensure the stability of the bank, and such.</td>
</tr>
<tr>
<td>Back-casting material or back-fill material of new or existing revetment</td>
<td>Reduction of the earth load makes it possible to reduce the size of the levee body, foundation, and sheet pile cross-section that can lead to reductions in cost and work period. The material can be used to prevent liquefaction of backfilled ground, seismic reinforcement of established structures and raising backfilled ground.</td>
</tr>
<tr>
<td>Revetment levee widening material and divider material</td>
<td>Because underwater placement is possible, levee-widening and dividers can be constructed at any location of the revetment. Also since there is no need of temporary roads and additional strength, reductions in cost and work periods may be achieved.</td>
</tr>
<tr>
<td>Surface improvement material of soft soil filled-in ground and backfill material around underwater structure</td>
<td>These materials can be used for surface improvement of soft soil filled-in ground and backfill material around underwater structures.</td>
</tr>
</tbody>
</table>

**CONSTRUCTION OF LARGE-SCALE PERIMETER BUND USING THE PM-CLAY METHOD**

This large-scale perimeter bund project in Southeast Asia was constructed using the PM-CLAY Method. The Project can be outlined as:
- **Volume of PM-CLAY**: about 3,000,000 m³
- **Maximum sea water depth**: -30 m (sea level)
- **Bund top elevation**: +4.5 m (sea level)

2. In this project, the perimeter bund was constructed with an inclined face of eighteen (18) degrees by direct placing of PM-CLAY without using any mold.

3. The hard clay, which was the main construction material of the perimeter bund, was provided from the in-fill area in this project. The layout of main equipment for the PM-CLAY Method is shown in Figure 3.

- **Inclination of bund slope**: 1:3 (A cross-section of the PM-CLAY bund is shown in Figure 2)
- **Material**: dredged natural clay, cement, seawater

**Project features**

The main features of this project are:
1. An unprecedented volume of 3,000,000 m³ PM-CLAY was placed at a level -30 m below sea level.

Figure 2. Cross-section of PM-CLAY bund.
**Construction method of perimeter bund**

The construction of the perimeter bund using the PM-CLAY method was carried out in two phases which consisted of trench placing and bund placing. PM-CLAY materials used were mainly natural clay, cement, and seawater.

- During the trench-placing phase, after completion of trenches as designed, PM-CLAY was being placed into the trench up to the seabed level. Construction above the seabed level was treated as bund placing.
- During bund-placing, a dike approximately 1.5-m high was placed on either one or both sides of the bund to prevent PM-CLAY from spilling off the bund. This method was done repeatedly until the desired shape was formed.

During the perimeter bund placing project, the perimeter bund was constructed using solidifying clay that was a comparatively difficult job when considering the characteristics of the material (locally produced clay) and requirements for the quality. If low-fluid PM-CLAY is used, and a large amount of PM-CLAY is placed at a fixed position, this causes a quality problem in the peripheral part of the PM-CLAY placement.

Therefore, PM-CLAY placement at one place at a time was limited to a certain amount and was carried out by moving the placing pipe (see Figure 4). In addition, PM-CLAY was placed by inserting the discharge port of the pipe into already placed PM-CLAY. This helps prevent separation of PM-CLAY during free fall. Figure 4 shows PM-CLAY placement. Figure 5 shows the construction overview of the perimeter bund.

**Dike construction**

Before construction of the bund, a dike with a height of approximately 1.5 m was constructed along the side of the PM-CLAY bund to maintain the designed bund shape and to prevent newly placed PM-CLAY from overflowing.

In this project, the dike was constructed by direct placing of PM-CLAY without using any molds. Normally, PM-CLAY was too soft to construct the dike. Therefore, the perimeter bund was placed by using stiff PM-CLAY, and
the placing pipe was accurately positioned for dike construction. After completing the dike, PM-CLAY placing was started. The placing filled up the gap in between the two dikes.

This method would be done repeatedly until the desired shape was formed. Figure 6 shows the dike construction method.

**Supply of raw material clay**
Placement tests using natural clay showed that the natural clay was not well mixed with the cement and seawater. Accordingly, natural clay was required to be loosened to a 3- to 5-cm slump to allow mixing well with PM-CLAY.

For improving the PM-CLAY production capacity, dredged natural clay was loosened beforehand by excavators equipped with a powerful mixing device, which were mounted on a pre-treatment vessel.

Loosened natural clay was sent to the PM-CLAY vessel. Both sides of the pre-treatment vessel allowed mooring of barges for natural clay transport. When the barge is brought alongside, the mixing bucket was lowered into the material barge and the mixing process would start (Figure 7).

**Installments of PM-CLAY vessels**
Construction of the perimeter bund under this project required lower fluid material than that of the solidifying clay used under the ordinary PM-CLAY method. Accordingly, two PM-CLAY vessels were constructed, which were
When placing stiff PM-CLAY to –30 m sea level, it was important to control accurate positioning of the placing pipe and achieving the end of placing pipe level for maintaining the good quality of the PM-CLAY.

The PM-CLAY vessel was equipped with two types of placing equipment: placing pipes (Figure 9) and a distributor. PM-CLAY placing pipes are used in deeper water from –30 mCD to –5 mCD and the distributor is used in shallow water from –5 mCD to +2.5 mCD.

For improving the moving speed of the placing pipe, an automatic vessel operation system was installed on the PM-CLAY vessel to manipulate the movement of the placing pipe.

**CONCLUSIONS**

The construction work was on a large-scale and this rapid construction project was unprecedented for the PM-CLAY Method.

Various equipment troubles were encountered in the beginning stages of the construction and time was spent fixing them. Finally, however, the equipment became fully operable as initially planned, and because of the efforts of the constructors the construction work was completed successfully.

The PM-CLAY Method helped reduce the need for local procurement of construction materials at the site area as it used PM-CLAY that is a mixture of natural clay, water and cement. It also reduced the need for securing disposal fields for soft clay and instead enabled it to be recycled.

The PM-CLAY Method is a proven and technologically advanced construction method which has been used extensively in Japan.

Actual construction results of the PM-CLAY Method will continue to be further accumulated in the future, both inside and outside of Japan. The exact location of the construction and the details of the construction conditions are not explicitly indicated in this report, partly to comply with the client’s request.

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**Table II. Specifications of PM-CLAY vessels.**

<table>
<thead>
<tr>
<th>Vessel name</th>
<th>RYUJIN</th>
<th>SENEI NO.17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal capacity (m³/h)</td>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td>Principal dimensions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length overall (m)</td>
<td>65.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Breadth (m)</td>
<td>26.0</td>
<td>23.5</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>4.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Draught (m)</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Excavator</td>
<td>10 m³/class</td>
<td>5 m³/class</td>
</tr>
<tr>
<td>Mixer</td>
<td>Type</td>
<td>Batch-type planetarium mixer</td>
</tr>
<tr>
<td>Capacity</td>
<td>4.5 m³×2nos</td>
<td>4.5 m³×2nos</td>
</tr>
<tr>
<td>Silo</td>
<td>500t×2nos</td>
<td>200t×3nos</td>
</tr>
<tr>
<td>Delivery pump</td>
<td>Piston, 500 m³/h×1no</td>
<td>Piston, 200 m³/h×2nos</td>
</tr>
<tr>
<td>Placing equipment</td>
<td>Distributor×1no</td>
<td>Distributor×1no</td>
</tr>
<tr>
<td></td>
<td>Placing pipe×1no</td>
<td>Placing pipe×1no</td>
</tr>
<tr>
<td>Generator</td>
<td>600KVA×3nos</td>
<td>600KVA×1nos</td>
</tr>
<tr>
<td></td>
<td>500KVA×1no</td>
<td>200KVA×1nos</td>
</tr>
</tbody>
</table>

*Figure 9. The placing pipe.*