Reuse of by-products as geo-materials in port construction in Japan

Kikuchi, Y.
Port & Airport Research Institute, Yokosuka, Japan

Keywords: port construction, dredged clay, back fill, granulated blast furnace slag, slag, coal ash

ABSTRACT: This paper introduces Japan's situation regarding the reuse of by-products as geo-materials for port construction. Characteristics required for the geo-materials used in port construction are first summarized. Then, an outline of the by-products used in port construction is presented. Finally, engineering issues and state of the art technologies of using dredged clay, iron slag, and fly ash which have intensively used in port construction are introduced.

1 INTRODUCTION

Port constructions are usually of a large scale. They need a large amount of construction materials in a short time. Most of these geo-materials had been provided from virgin natural materials until the early 1990s. On the other hand, some port construction such as the deepening and maintaining of ship lanes or basins produce a large amount of dredged soil. They have been used without treatment for the reclamation of man-made islands in port areas. Generally dredged soils are low quality materials for reclamation, because they contain a lot of water and are weak in shear strength. This method of utilization is not recommended.

Industrial zones have been located in port areas in Japan, and factories such as iron-foundry plants or heat power plants in industrial zones have produced large amounts of slag or coal ash. Japan has anticipated the utilization of such by-products in port areas.

As mentioned above, large amounts of by-products such as dredged soil, slag, and coal ash which can be used for geo-materials have been produced in port areas. However, it is usually difficult to intensively use them in their natural states, because they are low quality materials with whose original forms have large variations in terms of characteristics. If these materials can be changed to high quality materials with minimum treatment, they will be intensively used for geo-materials for port construction and reduce the use of natural resources. This kind of usage is promising for sustainability and maintains the environment. Methods for reusing of industrial and construction by- products have been studied in Japan from this point of view.

In this paper, the characteristics required for the geo-materials used in port construction are summarized at first. Then, outline of the by-products used in port construction is presented. Finally, engineering issues and state of the art of using dredged clay, fly ash, and iron slag which have intensively used in port construction are introduced.

2 PROPERTIES REQUIRED OF GEO-MATERIALS USED FOR PORT CONSTRUCTION

Figure 1 shows an image of the cross section of quay wall. In Japan, most port construction areas are covered with a thick weak clay layer, and they are usually improved with sand or other materials. A rubble mound is constructed on the top of the seabed to support caissons made of reinforced concrete. Sand is used to fill the caisson. Rocks are used to backfill the caisson to reduce the earth pressure against the caisson. Finally, back yard is reclaimed with soil. The required physical and mechanical characteristics of these geo-materials differ from where they are used.

Required characteristics for the backfill are mainly earth pressure reduction for the quay wall and the prevention of liquefaction. Figure 2 shows the change of the coefficient of active earth pressure $K_a$cosδ of sand. The change of calculated $K_a$cosδ is about a factor of 1.2 every 5 degrees of internal friction angle. Figure 3 shows the change of the total earth pressure of clay resulting from the change of cohesion. This figure shows the calculation results of the earth pressure acting on a wall with a height of 15m. In this case, total earth pressure can be ignored if the cohesion of the clay is higher than 120 kN/m^2.

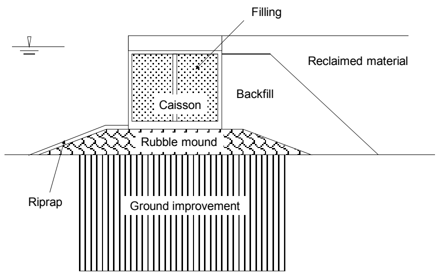


Figure 1. Example locations in which geo-materials are used for port construction.

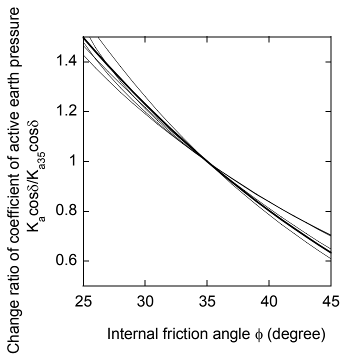


Figure 2. Changes of the coefficient of active earth pressure due to changes in internal friction angle.

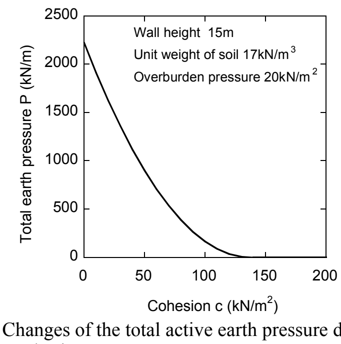


Figure 3. Changes of the total active earth pressure due to changes in cohesion.

As geo-materials used for backfill usually have large friction angles and geo-materials made of by-products seldom have large friction angles, we seldom use geo-materials made of by-products because of the high friction angle. In contrast, as cohesion can be easily controlled by solidification, geo-materials made of by-products for backfill are often solidified. Solidified geo-materials are also highly resistant to liquefaction, another preferable backfill characteristic.

Combining geosynthetics such as geo-sheets or geo-grids with geo-materials made of by-products is a promising techniques for reducing earth pressure to the walls.

As extremely large pressure will be repeatedly applied to the rubble mound supporting caissons, geo-materials used for the rubble mound should have large diameters, hard particles, and high shear strength. No man-made geo-materials suited for such an application are currently produced, but natural hard rocks are used.

There are several construction methods, including sand drains (SD), sand compaction piles (SCP), deep mixing method (DMM), and liquefaction prevention. The materials used differ by method.

SD method is a method to improve drainage by installing a sand pile on clay ground, while the SCP method is a method to make the ground more dense via sand piles (for sand layers), or by displacing weak clay with sand (for clay layers). The aims of SD and SCP methods are different but the materials used for both methods include sand or new geo-materials with a particle size similar to that of sand. Geo-materials made of by-products with similar particle diameter distributions or those controlled with the particle diameter distributions are often used instead of sand.

DMM is a method to solidify the ground by mixing solidifying agent and soil. Solidifying agents include ordinary cement or special cement specifically for this purpose. However, a new solidifying agent using fly ash was developed in order to control the solidified strength control (CDIT, 2002).

Fill for a caisson or a cell requires a large amount of geo-materials. The aim of a caisson fill is to increase the weight of the caisson, and a certain unit weight of geo-materials is required to do so. The aim of a steel cell fill is to improve the shear resistance of the steel cell, and, to do so, dilative geo-materials or high shear strength materials are required.

3 BY-PRODUCTS USED AS GEO-MATERIALS FOR PORT CONSTRUCTION

Table 1 shows the construction and industrial by-products studied to be used for port construction as geo-materials. The levels of utilization of by-products are affected by social demands or by research contents. New materials which are not in the table have potentials to be listed near future.

Here, we introduce developments in the utilization of the geo-materials such as dredged clay, iron and steel slag, and fly ash.

Table 1. By-products studied utilization for port facilities as geo-materials in Japan.

By-products			Output per year	Utilization purpose※
Construction by-product	Construction surplus soil		280 mil. ton	Backfilling (solidified), Filling, SD, SCP, Reclamation
	Dredged soil		40 mil. tons	Backfilling (solidified), Filling, SD, SCP, Reclamation
	Asphalt concrete mass		30 mil. tons	(Insufficiently studied)
	Concrete mass		35 mil. tons (more than 95% used for road beds)	(Used for backfilling and SD)
	Construction sludge		8 mil. tons	(Insufficiently studied)
Industrial by-product	Iron and steel slag	Slow-cooled blast furnace slag	25 mil. tons (1.1 mil. tons used for construction material)	Backfilling, Reclamation
		Granulated blast furnace slag		Backfilling
		Steel slag	12 mil. tons	Filling, SCP, Counterweight
	Non-ferrous metal slag	Cupper slag	2.5 mil. tons	Filling, SCP
		Ferro-nickel slag	2.9 mil. tons	Filling
	Coal ash	Fly ash	10 mil. tons (90% are used for cement material)	Backfilling (solidified), Deep mixing, SCP (granulated)
		Clinker ash	1 mil. tons	SCP
	Oyster shell		0.2 mil. tons	SCP
	Municipal waste slag		0.8 mil. tons	SCP
	Sewage sludge slag			SCP

* Utilization purposes are limited to geo-materials only. Pavement and concrete materials not included.

3.1 *Dredged clay*

Dredged soil is the largest construction by-product in port construction in terms of volume. As retaining the disposal site for dredged soil is getting harder, the effective reuse of dredged soil is the hottest issue. At this moment, 50% of dredged soil is directly used for reclamation, and 30% of it is effectively used.

There are many varieties of dredged soil, from hard rock to weak clay, but as a large amount of water is added to dredged soil when dredged, reclaimed land constructed by dredged soil is very soft and weak. Consequently, ground improvement is inevitably required for reclaimed land.

Techniques for effective use of dredged clay include stabilization, dewatering, and classifying. Of these, the most intensively studied is the stabilization technique. Solidification treatment – the improvement of the shear strength of the soil by adding a cementing agent – is the main treatment in stabilization. By this treatment, as dredged clay becomes a geo-material with a high void ratio and high consolidation yielding pressure, we can ignore the compressibility of the reclaimed layer, and reduce the settlement of the foundation ground. Central Japan International Airport island, a reclaimed offshore island, was constructed with 12 million m^3 of cement treated clay, by a method called the pneumatic flow mixing method (Kitazume & Satoh, 2003).

Active earth pressure to the retaining wall is reduced by the backfill with high shear strength, and it will be further reduced by the backfill with light weighted geo-materials. When cement is added to dredged clay with a high water content ratio, it turns into a geo-material with light weighted high shear strength. Furthermore, this material will be further lightened by adding air foam or expanded polystyrene beads (EPS). Figure 4 shows a magnified view of light weight cement treated clay with air foam, which is called SGM. When making light weight treated soil, lightening material should be well dispersed. Figure 4 shows that the air foam was well dispersed.

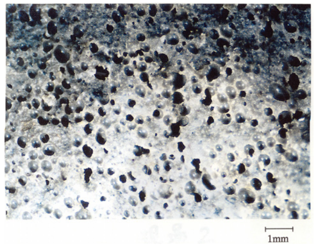
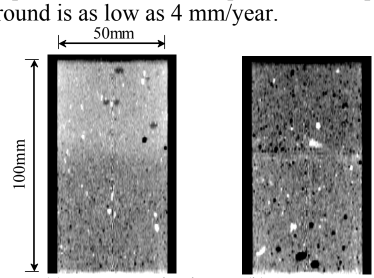


Figure 4. Enlarged photo of light weight cement treated clay.

As SGM will be used under the ground water table, it is understood that SGM will absorb water. Sampling was conducted on an SGM layer which was aged ten years at the time of sampling. It had been located above the ground water level and the surrounding soil was sufficiently wet. Figure 5 shows a CT image of the sample that was taken from near the top surface of the SGM. In the X-ray CT images, higher densities are lighter and lower densities are darker. The figure shows that the upper part of the sample, up to about 40 mm, is lighter than the other parts; this means that the density of that part was higher than that of other parts. Other investigations clarified that this change is caused by the absorption of water. The speed of absorption in wet ground is as low as 4 mm/year.



(a) 0-100 mm depth (b) 120-220 mm depth
Figure 5. X-ray CT images of a specimen sampled from a ten year old construction site.

The cement treated clay (CTC) had high shear strength, but one problem of CTC is that it is too brittle at failure. Adding tire chips derived from scrap tires to CTC has been shown to overcome this problem. Figure 6 shows the X-ray CT image of the horizontal cross section of the specimen during unconfined compression. Hair cracks were observed in the specimen with tire chips; on the other hand, no cracks were observed in the CTC specimen before the peak strength. However, no large cracks were observed in the specimen with tire chips, although large cracks were propagated in CTC after large axial strain. This difference in crack propagation enables a change in the failure mechanism of the CTC.

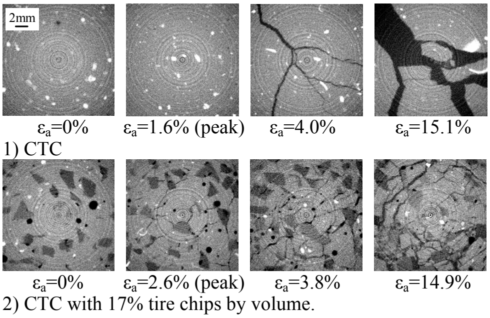


Figure 6. Crack propagation difference in standard CTC and CTC with tire chips during an unconfined compression test.

3.2 *Iron and steel slag and other types of slag*

Eighty-three percent of blast furnace slag was granulated in Japan. Granulated blast furnace slag (GBFS) is a sandy material with a light saturated unit weight of about 17 kN/m^3 and self solidification reacting with water. It is used mainly for backfill for port construction to reduce the earth pressure to the structure and residual settlement of the reclaimed land.

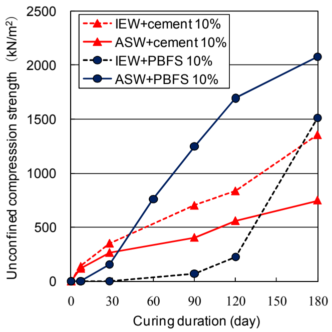


Figure 7. Unconfined compression strength change of GBFS by the difference of pore water and additive materials.

GBFS was first used as an alternative to sand. However, follow up investigations to GBFSs used for backfill clarified that they had been solidified (Kikuchi et al. 2004). Consequently, GBFS is considered for use in materials with solidified strength when used for backfilling. GBFS is required to be solidified within a certain period of time after the construction; for that purpose, additives are used to accelerate solidification of GBFS. Figure 7 shows the experiment results for this kind of research. In this experiment, cement and powdered BFS (PBFS) are used for additives. Pore waters are selected to iron-exchanged water (IEW) and artificial seawater (ASW). A combination of ASW and PBFS is preferable to solidify GBFS if it is used for backfilling of port facilities.

Because of the lack of sandy materials for construction in Japan, several materials such as steel slag, non-ferrous metal slag, municipal waste slag, and granulated fly ash are currently in use as a sandy material.

3.3 *Coal ash*

Ninety percent of coal ash is fly ash. The particle size of fly ash is the range of silt. Therefore, it is not suitable as geo-material for construction. Adding shear strength by adding cement will increase the shear strength of the fly ash and it will be a preferred geo-material for backfilling. Figure 8 shows a dramatization of cement treated fly ash (CTFA) used as backfill. CTFA was used in a trapezoidal shape. It is anticipated that using fly ash will not only reduce earth pressure to structures, but also improve earthquake resistance.

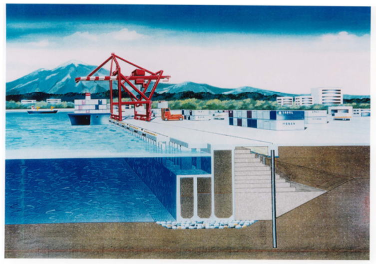


Figure 8. Dramatization of cement treated fly ash backfill.

4 CONCLUSION

This report introduced the Japanese situation of the reuse of by-products as geo-materials for port construction. Treatment of by-product should in principle be minimized, and utmost attention should be paid to ensure that people and the earth suffer no adverse effects due to the use of by-products.

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