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LAND RECLAMATION USING CALCIUM OXIDE (CaO) IMPROVED SOIL IN JAPAN

ABSTRACT

In recent years, great quantities of dredged material have been removed in order to maintain the depth of channels and anchorages. In addition, a lack of land for the disposal/storage of dredged soil has become a problem. At the same time, converter slag that has properties such as wear resistance or hydraulic properties has been used as a civil works material in areas such as roadbeds.

With the reduction of public construction recently, however, the development of new usages is expected. Therefore, in coastal areas the utilisation of a Calcium Oxide (CaO) improved soil, i.e., dredged soil and converter slag (usually called "slag stabilised soil") has been developed. From previous studies, characteristics such as hardening and a suppressed increase in pH is known. This improved soil is used as material for the "padding" of tidal flats and marine forests and for backfilling hollows where a large quantity of sand from the sea bottom has been placed for urban development.

Based on an experiment using a pneumatic flow mixing method where slag stabilised soil was used as a material for reclamation, large-scale rapid reclamation work was performed with the aim of satisfying an average strength of 50kN/m^2 (long-term curing). At the same time it was confirmed that there was no adverse influence on the water quality in the peripheral sea area during the reclamation period.

An article on this subject was first published in the *Proceedings of the Western Dredging Association (WEDA XXXIII) Technical Conference and Texas A&M University (TAMU 44) Dredging Seminar*, Honolulu, Hawaii, August 25-28, 2013 and is reprinted here in an updated version with permission.

INTRODUCTION

Great quantities of dredged soil have been produced from maintaining the depth of channels and anchorages and for harbour developments. This has previously been caste onto land designated for the disposal of dredged soil or in reclaimed areas. However, it has recently become difficult in some places to secure sufficient land whilst in other areas availability has decreased because of the recent developments in environmental conservation.

Converter slag is the granular by-product of steel production and is produced at an approximate rate of 10 million tonnes a year in Japan. It has properties such as wear resistance and hydraulic properties when being used as a civil works material in areas such as road beds. It is generally considered a useful way of recycling material. However, when converter slag is used in a marine area, particularly a place where it is directly in contact with seawater, it is necessary to consider its influence on the neighbouring environment because alkalinity levels are high in converter slag (Ref 1).

The slag stabilised soil increases the dredged soil's strength and the combination of the two materials suppresses the liquidation of the alkali from the converter slag. It is thought that the mixture also adsorbs phosphorus contained in the eutrophic dredged soil. Because seawater does not circulate in the sea hollows, they become a degraded

Above: A pneumatic conveying vessel at work. A pneumatic flow mixing method, in which slag stabilised soil was used as a material for reclamation, allowed for large-scale, rapid reclamation work. Tests confirmed that there was no adverse influence on the water quality in the peripheral sea area during the reclamation period.

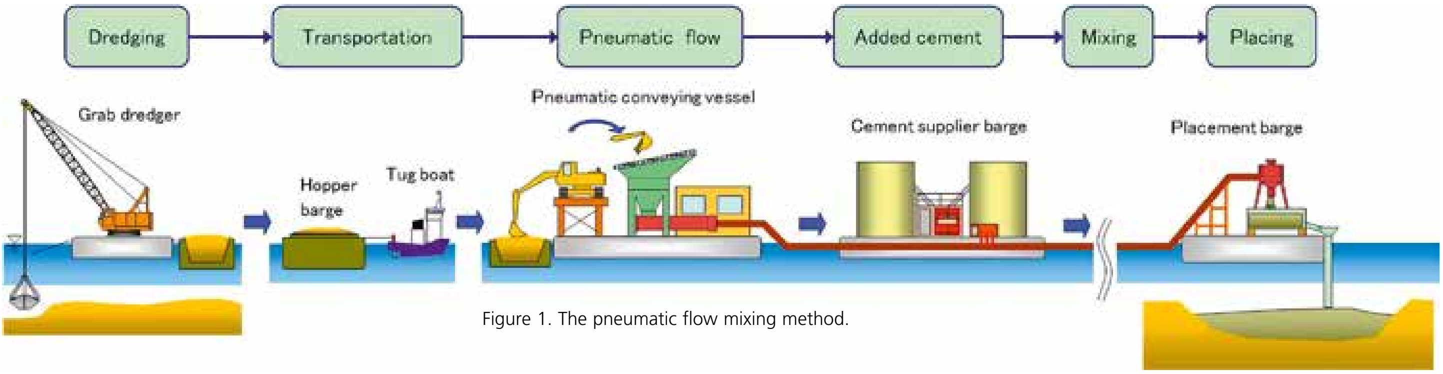

Figure 1. The pneumatic flow mixing method.

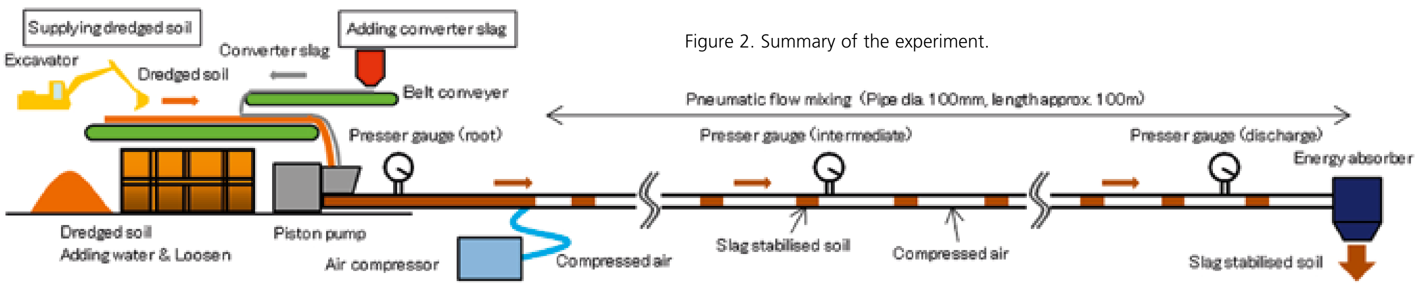

Figure 2. Summary of the experiment.

environment with a lack of oxygen and a high density of hydrogen sulfide. It is possible for slag stabilised soil to be utilised as a possible material backfill for hollows and to create shoals and tidelands in marine areas.

In this report, the slag stabilised soil was examined for its hardening character and basic experimental data were collected while using it as a material for reclamation. The large-scale reclamation work was accomplished using the pneumatic flow mixing method, a first for the Japanese.

The reclaimed land formed by the slag stabilised soil was evaluated for its performance and construction properties so as to establish a technique for slag stabilised soil. At the same time the reclamation work was managed appropriately so as not to affect the neighboring environment (Ref 2).

PNEUMATIC FLOW MIXING METHOD

The pneumatic flow mixing method is characterised by the following steps. First, dredged soil obtained from grab dredging undergoes the addition of a stabilising agent as the soil is unloaded from a pneumatic conveying vessel. The dredged soil is mixed with a stabilising agent by utilising the turbulent effects caused by the plug flow that can be generated in a pneumatic conveying pipe.

Figure 1 provides an example of the configuration of the working fleet used for this process. The fleet comprises a grab dredger, hopper barge, pneumatic conveying vessel, cement supplier barge, and a placement barge (for underwater placement). Construction carried out using this method is primarily characterised by the preparation and placement of stabilised soil and is carried out by all these vessels working together (Ref 3).

Figure 3. Left, placement on the ground; right, placement in the water.

EXPERIMENT

Summary

In the case of reclamation with slag stabilised soil, it was confirmed that the pneumatic flow mixing method was applicable to the mixing of dredged soil and converter slag, and work proceeded to acquire basic experimental data at the time of the large-scale reclamation. The mixing of the two materials and placement were the subject of experiments in September, 2010 in Tokai-shi, Aichi using the pneumatic flow mixing method with a pipe diameter φ of 100 mm and pipe length of approx. 100 m.

The basic layout summary for the experiment is shown in Figure 2. The experimental conditions assumed the water content ratio of dredged soil was 1.6 times the liquid limit of the soil, and the additional quantity of converter slag (grain size 25 mm or less) made up 30% by volume of dredged soil.

The placement on the ground was by an energy absorber and the water placement by using a tremie. This was performed in order to compare the influence of the mixtures using different placing methods. The situations in relation to the placement on the ground versus in the water are shown in Figure 3. The uniaxial compression test on a sample of slag stabilised soil in each pit was done on the 28th day after placement. In addition, the depth distribution of strength for the slag

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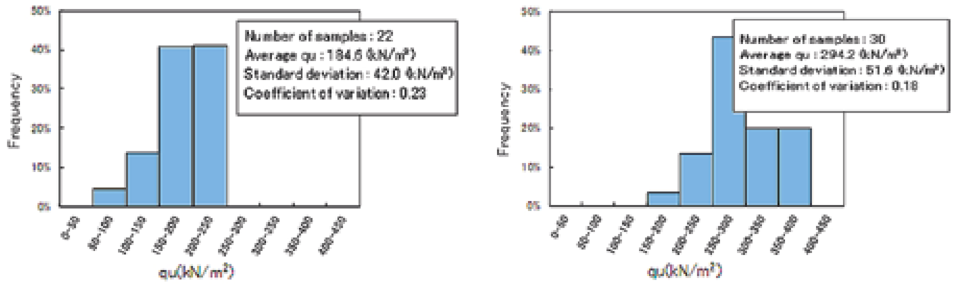


Figure 4. Left, Uniaxial compressive test (ground); right, Uniaxial compressive test (water).

stabilised ground at a 2-m depth was confirmed by carrying out a cone penetration test and a standard penetration test on the 28th day and six months after placement.

Strength characteristic

The results of uniaxial compressive tests of slag stabilised soil (at age 28 days) are shown in Figure 4. They show average uniaxial compressive strength (qu) is 294.2 kN/m^2 and coefficient of variation is 0.18 in case of placement on the ground. An average qu of 184.6 kN/m^2 and coefficient of variation of 0.23 is the case for placement in the water and it was confirmed that dredged soil and converter slag were able to be mixed uniformly by the pneumatic flow mixing method. The qu28 was 279.1 kN/m^2 in the indoor test using the dredged soil was the same as the experiment.

The ratio for qu when placed on the ground and the indoor test was 1.05 and the one for water placement was 0.66. The ratio between ground and water was 0.63 (Ref 4). The ratio of qu was bigger and the coefficient of variation was smaller than the value shown in the technical manual for the pneumatic flow mixing method (ratio of qu (ground) 0.7, ratio of qu (water) 0.5, coefficient of variation 0.35) (Ref 5).

Ground exploration

With the slag stabilised ground, an electric cone penetration test, a standard penetration test and an automatic lamb sounding were done. The depth distribution of the point resistance qt of the cone penetration test, the uniaxial compressive strength qu, the standard penetration test N value and the automatic lamb sounding Nd value of the 28th day after placing are shown in Figure 5. There was no material separation based on differences in specific gravity and deterioration of the quality owing to surface drying on the slag stabilised ground. It was also confirmed that the ground where the depth distribution of strength was undertaken had formed uniformly (Figure 6). In addition, from these results, the expression of relations of uniaxial compressive strength qu and corn index qc was qc = 12.1× qu (Ref 6).

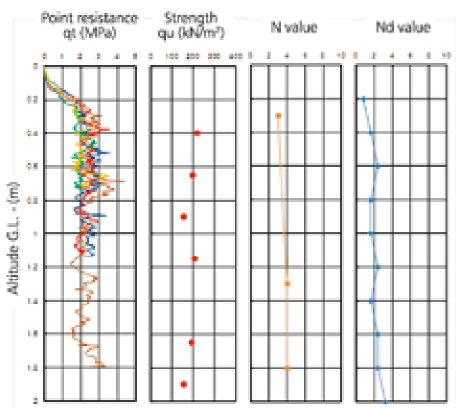


Figure 5. The depth distribution of strength (at age 28 days).

Figure 6. Left, Slag stabilised ground (during placement); and right, slag stabilised ground a year later.

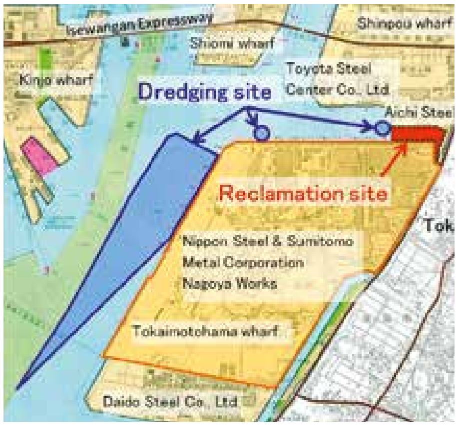


Figure 7. Site location map.

Table I. Outline summary.

Construction name	North Tokaimotohama wharf public waters reclamation
Client	Nippon Steel & Sumitomo Metal Corporation
Contractor	Goyo・Toyo・Toa・Wakachiku joint venture
Contract period	2011/9/5 ～ 2014/4/30
	Reclamation (eastern) 2012/4～5 (completion)
	(western) 2013/3～9 (schedule)
Amount	Reclamation: 515,200 m^3
	Converter slag (grain size 25mm or less): 386,400 ton
	Dredging (3 places): 320,000 m^3
	※Additional quantity of converter slag was 25 vol. % of dredged soil

Table II. Investigation components.

Item	Content
Dredged soil	Soil test※, Loosing test, Normal management test※
Converter slag	Water content ratio※, Mass per unit volume※
Slag stabilised soil	Characteristic examination※, pH test※、Normal management test※, Elution test, Component test※
Neighboring environment	Turbidity/pH measurement※, Noise measurement, Odor measurement
Construction	Pressure in delivery pipe※, Quantity of soil deliver/added converter slag/added water※, Placing area and slope angle
Investigation	Uniaxial compressive test (sample of placing location)※, Cone penetration test※, Automatic lamb sounding※, Block sampling, Gel push sampling, Surface wave exploration, subsidence measurement, pH measurement, Pile driving examination, Loosing and compaction test

LARGE-SCALE RECLAMATION WORK

Construction summary

The reclamation work of the eastern area was carried out from April to May of 2012 using the pneumatic flow mixing method.
A construction summary, site locality map, construction flow diagram, site plan, the eastern reclaimed area and second placement facility are shown in Table I, Figures 7, 8, 9 and 10. Mixed slag stabilised soil was stored temporarily in a vessel and was transferred by concrete pumps to each location.

Investigation contents

The properties of the reclaimed ground and the strength of the slag stabilised soil which was placed in the eastern area to establish techniques for the material were investigated. An investigation components list is shown in Table II.

Investigation results

In this report, only the results for ※ marks in Table II have been written down which are necessary for a performance evaluation of standard construction management items and the reclaimed ground.

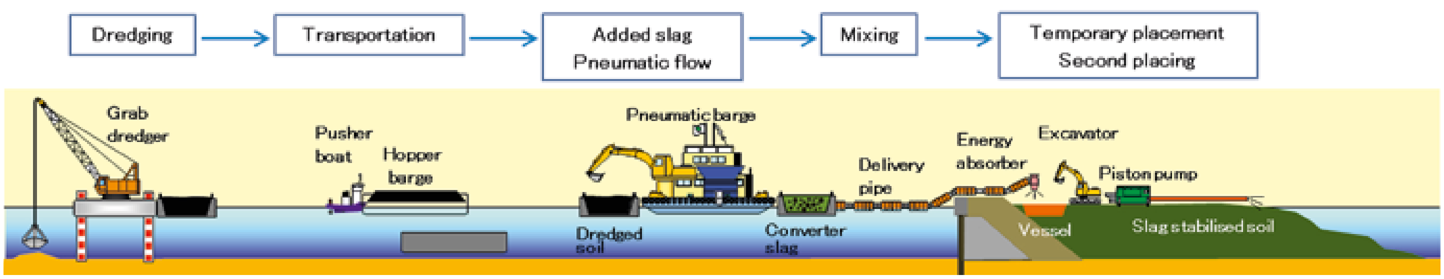
a) Soil test

The dredged soil that was mixed with the converter slag used dredged soil I (11,323 m^3), dredged soil II (7,949 m^3), dredged soil III (4,763 m^3). There was mostly silt and clay in dredged soil I, and there was mostly sand in dredged soil II and III.

b) Normal management test of dredged soil

Water content and wet density, flow value (JHS A 313) of the dredged soil in every hopper barge were measured. Dredged soil I had low wet density and high water content, but flow values tended to become smaller (around 100mm) regardless of water content and wet density ratio. Dredged soil II had a high wet density and the flow value was changed greatly according to the change of water content ratio. Dredged soil III had high

Figure 8. Construction flow diagram.



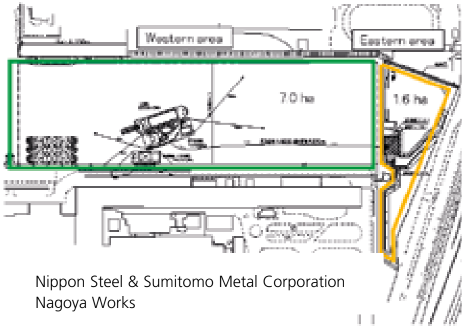


Figure 9. Site plan.

Figure 10. Left, Second placement facility; right, Eastern reclaimed area.

Table III. Soil test results

Item			Dredging site Unit	Dredged soil I April 2012	Dredged soil Ⅱ May 2012	Dredged soil Ⅲ April 2012
Density of the soil grain		ρs	g/cm³	2.644	2.648	2.654
Consistency	Liquidity limit	wL	%	109.8	58.5	58.9
	Plasticity limit	wP	%	38.5	31.9	25.9
	Plasticity index	IP		71.3	26.6	33.0
Grain size	Gravel	-	%	0.14	12.44	2.10
	Sand	-	%	13.80	53.60	52.20
	Silt	-	%	70.20	20.00	35.40
	Clay	-	%	15.90	13.96	7.40
	Max. grain size	-	mm	9.5	26.0	19.0
Wet density			g/cm³	1.303	1.636	1.719
Ignition loss		Li	%	11.6	8.5	5.0
Soil suspension pH			-	8.0	8.8	8.3
Natural water content		wO	%	171.3	73.3	63.0
Liquidity limit ratio		wO/wL	-	1.56	1.25	1.07

Table IV. Test result of dredged soil.

Item / D.S.	Wet density g/cm³		Flow value mm		Water content ratio %	
	Min., Max.	Ave.	Min., Max.	Ave.	Min., Max.	Ave.
D.S. Ⅰ	1.301～1.525	1.380	90.0～115.0	99.0	86.3～177.1	135.0
D.S. Ⅱ	1.500～1.812	1.715	86.0～143.0	113.5	40.5～92.7	54.0
D.S. Ⅲ	1.530～1.692	1.621	113.0～211.0	166.6	54.7～100.6	71.0

wet density with a tendency for the flow value to be comparatively high in regard to the water content ratio.

(c) Water content ratio of converter slag

The water content ratio was measured once a day with an infrared water meter. Measurement results are shown in Table V. It was uneven due to the influence of the rain during the reclamation period, but a water content of converter slag was bigger than the absorption water rate with an average of 8.3% (5.3% at the minimum and up to 10.5%.)

(d) Mass per unit volume of converter slag

The mass per unit volume of the converter slag was measured twice a day using a 10L container. The measurements were distributed over the range of 1.86-2.12, the average was 1.95.

(e) Normal management test result

The slag stabilised soil in the vessel was sampled during a reclamation period and the measured wet density, flow value and uniaxial compressive strength measured once a day. The designed value of the uniaxial compressive strength was 30 kN/m² and the aimed for strength prior to the indoor test result (strength ratio 0.6 during ground and water placement) (Ref 4) was an average of 50 kN/m² (when placed on the ground). The results for wet density, flow value and uniaxial compressive strength are shown in Table V.

Adjustments were made by adding water through the axis, sealing water on the pneumatic conveying vessel at a minimum so as to achieve the aimed for strength and satisfactory strength in all dredged soil in the third month after placement. In the technical

Table V. Test result of slag stabilised soil.

Item / D.S.	Wet density g/cm³		Flow value mm		Water content ratio %		qu kN/m²	
	Min., Max.	Ave.	Min., Max.	Ave.	Min., Max.	Ave.	Min., Max.	Ave.
D.S. I	1.655～1.933	1.927	87.0～117.0	96.5	31.5～85.2	32.2	21.0～116.0	126.8
D.S. II	1.851～1.996	1.780	83.0～112.0	91.4	25.7～49.9	49.4	64.6～199.0	73.0
D.S. III	1.822～1.931	1.884	99.0～140.0	120.7	37.0～51.0	44.9	15.0～86.8	41.5

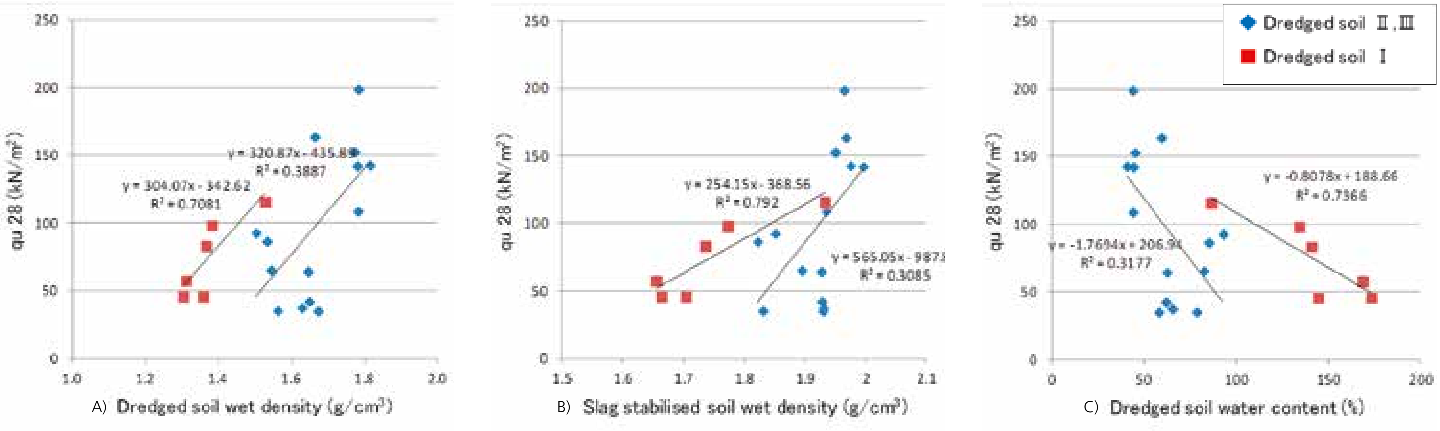


Figure 11. A) Relationship between wet water density of dredged soil and qu28; B) between wet water density of converter slag and qu28; and C) between content ration of dredged soil and qu28.

manual for the pneumatic flow mixing method (revised version), it was said "the dredged soil that included more than 50% (Ref 7) sand and that deviated from the coverage of 90mm - 100mm or more was desirable for the flow value"(Ref 8).

However, the slag stabilised soil included more than 50% sand and the flow value of around 80 mm, was able to be conveyed at this time. Relationships between the wet density of dredged soil, wet density of converter slag, water content ratio of dredged soil and qu28 are shown in Figure 11. Relationships between qu3, qu7 and qu28 are shown in Figure 12. A positive correlation was seen in the relationship between wet density of the dredged soil and qu28. A negative correlation was seen in the relationship between the water content ratio of dredged soil and qu28. In addition, it was confirmed that qu28 was able to be predicted from qu3 and qu7 because a positive correlation is seen between qu3, qu7 and qu28.

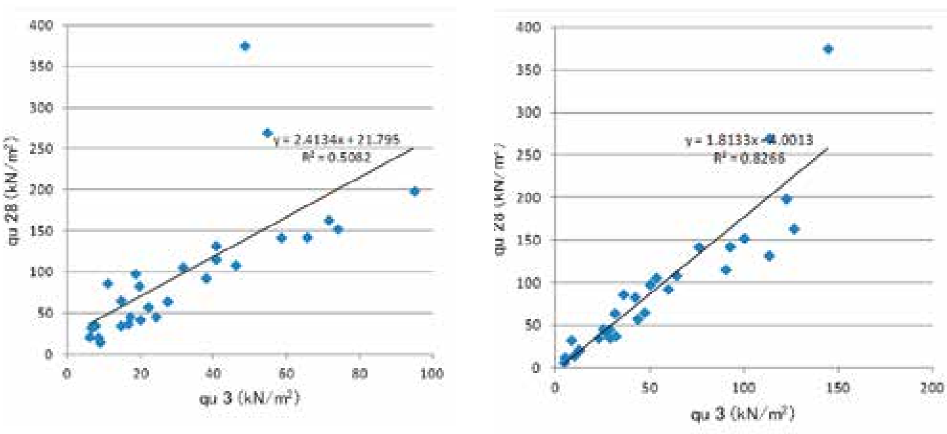


Figure 12. Left, relationship between qu3 soil and qu28; right, relationship between qu7 soil and qu28.

(f) Characteristic examination

Uniaxial compressive strength was measured for more than 20 specimens in each condition to confirm the change in the property of slag stabilised soil and the difference in dredged soil (Figures 13 and 14). The coefficient of variation of qu28 was up to 0.24 (April 25th) except in the early period of reclamation work and it was smaller than the 0.35 guidance figure given in the "the technical manual for pneumatic flow mixing method" (Ref 5).

(g) pH measurement

It was confirmed that the pH of slag stabilised soil was not beyond 9.0 which is the waste water regulation. Also once a day a check was made to see whether cloudiness occurred with natural seawater. The pH of the slag stabilised soil was on average 8.4. It rose around 0.2, but it was still less than 9.0. In addition, by measurements 30 minutes later, the cloudiness (separation of magnesium hydroxide) on the surface of the slag improved the soil and the cloudiness of the seawater could not be recognised (Figure 15).

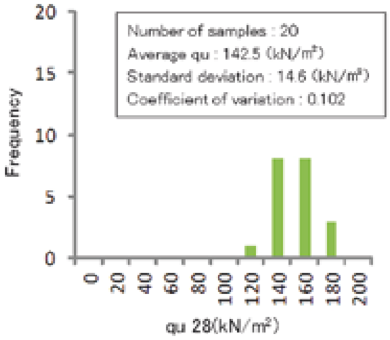


Figure 13. Strength distribution of qu28 (dredged soil I).

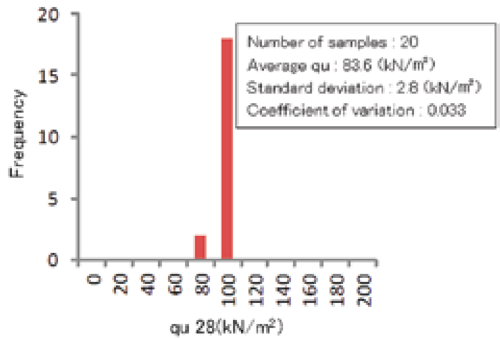


Figure 14. Strength distribution of qu28 (dredged soil Ⅱ).

Pack a container (ø 80 mm x H 50 mm) with a sample at 40 mm in height and level the surface flatly (approx. 300 g)

↓

Soak calmly a container into artificial sea water of the mass 10 times as large as a sample (using a 3L beaker)

↓

Stir a container 10 times at the rate of once per second within from 30 minutes to 3 hours after soaked, and measure a pH and observe the surface cloudiness

Figure 15. Measurement procedure (Ref 9).

value of the cement stabilisation (Ref 11) is shown in Figure 17. The remarkable rise in pressure was not seen this time in the pneumatic conveying of the slag stabilised soil (pipe dia. ϕ 800 mm × length 300 m) and it was confirmed that it had the same efficiency as the cement stabilisation.

(h) Elution examination, component examination

It was confirmed that slag stabilised soil complied with the bottom soil standard of the Marine Pollution Prevention Law and the quantity standard for elution and content of the Soil Contamination Countermeasures Act. The result of having carried out this component examination and an elution examination of the toxic substance using slag stabilised soil 28 days after placement as a sample showed that they were less than the standard for all items.

(i) Measurement of turbidity and pH

Turbidity and pH were measured once a day with a multi-parameter water quality meter. To comply with the water quality regulation the measured values for a background spot and a monitoring spot are shown in Figure 16 and Table VI. In regard to the cloudiness, turbidity was changed to SS by a correlative expression of the turbidity - SS which was carried out beforehand. The SS value went up and down under the influence of the rain, but because the value of background (BG) spot and the monitoring spot changed in the same way, and the pH was stable during the construction period. Both the pH and SS remained less than regulation values.

(j) Pressure in delivery pipe

Pressure sensors were installed in the pipe on the pneumatic conveying vessel and near the tip of the delivery pipe. These measured pressure in the pipe. The relationship between the flow value of slag stabilised soil and pressure incline, former experimental value (Refs 4, 10) and this measured value and

(k) Quantity of soil delivery, with added converter slag and added water

The quantity of dredged soil (in the barge) reclaimed by this construction equipment was up to 1456 m³ per day and up to 158 m³ per hour. The quantity of added converter slag was approximately as planned (25%) and was stable with an average of 25.2%, a minimum of 24.3% and up to a maximum of 25.7%. The quantity of added water at the axis seal

Figure 16. Monitoring spot

▲ Background spot.
● Quality of the water monitoring spot

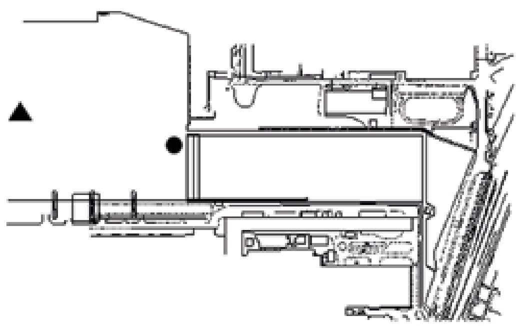


Table VI. Quality of the water regulation and the measured value of pH and SS.

Item	Quality of the water regulation value	BG spot	Monitoring spot
pH	5.0～9.0	7.9～8.2	7.9～8.2
SS	Below BG value＋10mg/l	3.9～39.2	3.9～41.3

Table VII. Result of uniaxial compression test.

D.S. \ Item	qu28 kN/m²				qu81 kN/m²			
	Mold		Polyvinyl chloride pipe		Mold		Polyvinyl chloride pipe	
	Min., Max.	Ave.	Min., Max.	Ave.	Min., Max.	Ave.	Min., Max.	Ave.
D.S. Ⅰ	57.9～98.5	80.0	28.1～87.2	61.9	120.4～144.1	132.3	131.8～217.9	174.9
D.S. Ⅱ	64.6～142.5	103.6	102.2～150.4	126.3	112.6～197.4	155.0	132.6～221.9	177.3
D.S. Ⅲ	35.5～65.6	47.9	27.4～75.6	47.9	60.3～148.2	96.2	53.7～196.9	107.9

of the pneumatic conveying vessel was given top priority for quality purposes and was reduced as much as possible to around 20 m³/h. The volume of slag stabilised soil became 1.48 times the quantity of natural ground soil after finally adding water and converter slag.

(l) Uniaxial compressive strength (sample at the placing location)

The slag stabilised soil was sampled before the second placement, molds were filled for measurements and sampled after the second placement by using polyvinyl chloride pipes and the strength development situation confirmed by a uniaxial compression test. The setting and the collection of the polyvinyl chloride pipes are shown in Figure 18.
The comparison of the uniaxial compressive strength between the field sample and the mold sample is shown in Table VII. The mold sample results showed that the measurement result for the field samples became an equal or bigger value.

(m) Core penetration test and automatic lamb sounding

An electrical static core penetration test and an automatic lamb sounding in eight places on the slag stabilised ground were carried out in order to grasp its strength properties in the first month and third month after reclamation was completed. The cone penetration test situation and the lamb sounding situation are shown in Figure 19. The test results that were measured are shown in Figure 20. Unevenness of the strength at each spot was seen, but strength increased according to the progress of the time and it was confirmed that the aimed for strength was reached to the same extent as the molded samples and the polyvinyl chloride pipe samples three months later.

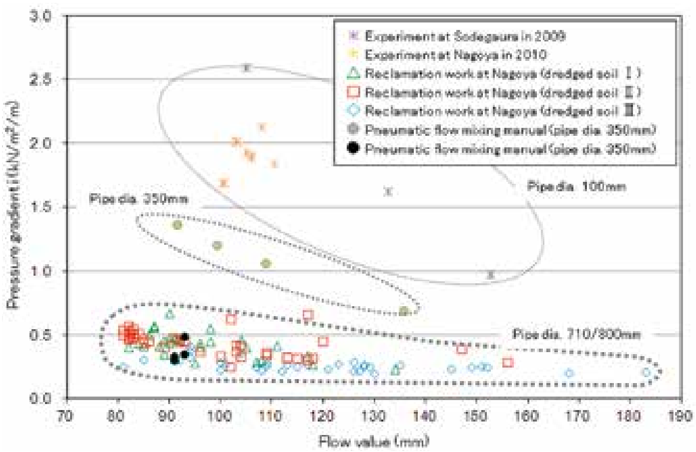


Figure 17. Relationship between flow value of slag stabilised soil and pressure incline.

Figure 18. Left, Setting situation of the polyvinyl chloride pipe; right, Collection situation of the polyvinyl chloride pipe.

Figure 19. Left, Core penetration test situation; right, lamb sounding situation.

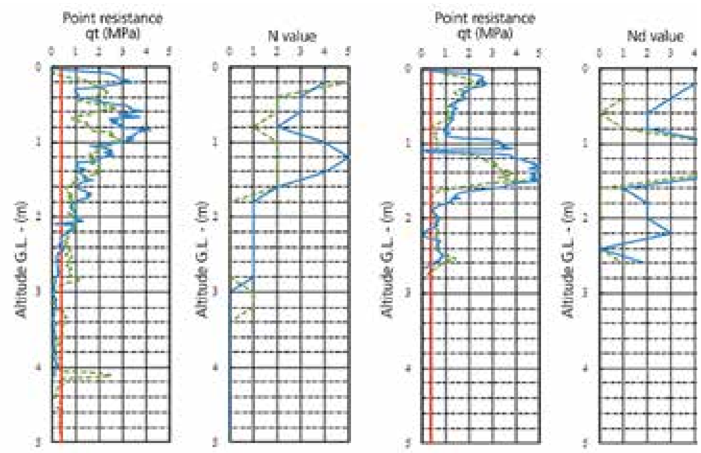


Figure 20. The ground findings.

CONCLUSIONS

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During this construction work the following things about the materials and construction properties of the slag stabilised soil were grasped:

(1) The uniaxial compression test and cone penetration test were carried out and they confirmed that the slag stabilised ground met the predetermined strength.

(2) Because a) there was a positive correlation between wet density of the dredged soil and uniaxial compressive strength, b) there was a negative association between water content ratio of dredged soil and its strength, c) there was a positive association of strength between short-term curing and 28-day curing, d) measurement of wet density, water content and uniaxial compression strength on site (at 3 days and 7 days) made it possible to estimate the strength of material (at 28 days).

(3) When the slag stabilised ground was constructed using the pneumatic flow mixing method, the coefficient of variation was 0.23 (experiment) and 0.24 (construction),which was smaller than the value (0.35) for stabilisation with cement and good ground material was realised. In addition, the strength ratio of the indoor examination results and the placing to the ground/water was 1.05/0.63 which were bigger than the values (ground: 0.7, water: 0.5) of the cement stabilised soil.

(4) By examining the pH, elution components of slag stabilised soil its safety was confirmed. It did not affect the neighbouring environment during construction; confirmed by measurement of pH and SS in the monitoring spot.

(5) The technical manual for the pneumatic flow mixing method (revised version) states: “the dredged soil that included more than 50% sand and that deviated from the coverage (Ref 7) of 90 mm-100 mm or more was desirable for the flow value (Ref 8)”. However, the slag stabilised soil included more than 50% sand and flow value was around 80 mm, but it was still able to be conveyed. The particle size distribution shifts to a wider range by adding converter slag. However, for the slag stabilised soil, it is thought that conveyance was still possible even if the flow value is relatively small. The conveying efficiency, the quantity of adding water and the quality of slag stabilised soil are related closely and the most suitable set point in consideration of construction condition of the slag stabilised soil and quality of dredged soil must be developed.

Reclamation work in the western area is planned next, and the aim is to improve the quality and construction performance for this next area based on the results to date. In addition, the plan is to use a mixing method unlike the pneumatic flow mixing method.

Then, as more knowledge is accumulated through the acquisition of various data and development of new methods of mixing, new usages will be found for slag stabilised soil. The aim also is to test and further promote the use of slag stabilised soil.

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