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Construction of Tideland by CaO Improved Soil

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Abstract

"CaO-improved soil" suits with construction material of tideland, because of its safety and decreasing turbidity characteristics. We examined safety of material, decreasing of turbidity and marine environmental monitoring in site. As a result, 1) "CaO-improved soil" is safety for heavy metal and poison. 2) Compared with dredged soil, "CaO-improved soil" decreased of about 70% of turbidity of putting in water. 3) Wave resistance of "CaO-improved soil" is stronger than dredged soil. 4) The restoring borrow pits is effective for solution of source of oxygen deficient water killing. It is possible to make good fishery by construction mound of tideland with "CaO-improved soil".

1. Introduction

In recent years, the demand for construction of shoals and tidelands has been increasing, especially in the fishing industry.[1)] A tideland refers to the land consisting of sand and mud, which appears in a coastal area at low tide. Tidelands not only afford many different species of marine life an important spawning and breeding ground but also help clean the seawater as bivalves, benthos, etc. decompose substances, which flow into the sea from the land area. In particular, the littleneck clam and other species of bivalves, which widely inhabit tideland, can improve the quality of seawater appreciably. A shoal is a shallow sea area adjoining a tideland. Since a shoal is supplied with various nutrient salts from the land area and with sufficient light from the sun, a wide variety of living things—seaweeds, algae, fishes—are found there. Similar to tidelands, shoals help improve the quality of seawater through the activities of these living things.

In the past, as a result of the reclamation of a large tract of land from the sea, shoals and tidelands disappeared noticeably, causing substantial habitat loss to marine life. Consequently, the need to restore the lost shoals and tideland is strongly desired, especially by the people involved in fisheries. The CaO-improved soil described in this report is considered a suitable material for construction (restoration) of shoal and tideland because it is safe and does not cause the seawater from becoming turbid much during execution of the work. In relation to the usefulness of the CaO-improved soil as a material for construction of shoal and tideland, we verified that the soil was safe and that it did not pollute the seawater remarkably during execution of the construction work, using the soil in an actual sea area and monitoring the progress of the work from the beginning till the end, as described below.

2. Safety

2.1 Impact on the environment

Table 1 shows an example of the results of an elution test of the CaO-improved soil. The levels of harmful substances eluted from the CaO-improved soil were lower than the levels of "tentative criteria" that were set for execution of the Environmental Technology Verification (ETV) Project of the Ministry of the Environment on the basis of the benthic sediments standards of the Law on the Prevention of Marine Pollution and Maritime Disaster (the so-called Marine Pollution Prevention Law). The elution of heavy metals was also on a safe level. In addition, even when dredged soil was mixed with CaO improver, the elution of harmful substances from the soil did not increase significantly.

2.2 Impact on living things

The CaO-improved soil was subjected to an acute toxicity test in accordance with the "General Report on Study & Investigation of Water Quality Standards for Fishes & Shellfishes" (Guidelines on Toxicity Tests of Marine Life: Fisheries Agency, March 2000) and the "Guidelines on Toxicity Tests of Marine Life: Fisheries Agency, March 2010." The test was performed using JIS K 0058-1: Methods for Testing Chemical Substances in Slags—Part 1: Method of Testing Amounts of Elution. Specifically, red sea breams, black abalones, and prawns were kept for 96 hours in the test waters that were prepared from an eluate (undiluted test liquid) obtained using CaO-improved soil and filtered seawater and diluting it to several differ-

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Table 1 Dissolution test of poisonous material of CaO-improved soil

		Result	Criteria
R-Hg	mg/L	<0.0005	<0.0005
Hg	mg/L	<0.0005	<0.005
Cd	mg/L	<0.002	<0.1
Pb	mg/L	<0.01	<0.1
Organophosphorus compound	mg/L	<0.01	<1
Hexavalent chromium	mg/L	<0.04	<0.5
As	mg/L	<0.005	<0.1
CN	mg/L	<0.01	<1
PCB	mg/L	<0.0005	<0.003
Organochlorine compound	mg/kg	<4	<40
Cu	mg/L	<0.05	<3
Zn	mg/L	<0.05	<5
F	mg/L	0.1	<15
Trichloroethylene	mg/L	<0.001	<0.3
Tetrachloroethylene	mg/L	<0.001	<0.1
Be	mg/L	<0.01	<2.5
Cr	mg/L	<0.03	<2
Ni	mg/L	<0.05	<1.2
V	mg/L	<0.05	<1.5
Dichloromethane	mg/L	<0.001	<0.2
Tetrachloromethane	mg/L	<0.0002	<0.02
1,2-Dichloroethane	mg/L	<0.0004	<0.04
1,1-Dichloroethylene	mg/L	<0.001	<0.2
cis-1,2-Dichloroethylene	mg/L	<0.001	<0.4
1,1,1-Trichloroethane	mg/L	<0.001	<3
1,1,2-Trichloroethane	mg/L	<0.0006	<0.06
1,3-Dichloropropylene	mg/L	<0.0002	<0.02
Thiram	mg/L	<0.0006	<0.06
Simazine	mg/L	<0.0003	<0.03
Benthiocarb	mg/L	<0.002	<0.2
Bensen	mg/L	<0.001	<0.1
Se	mg/L	<0.002	<0.1
Dioxin	pg-TEQ/L	0.0017	<10

ent concentrations. Note that when the undiluted test liquid or low-concentration test waters were used, a pH-controlled zone was provided so as to preclude the influence of pH. The black abalones used in the test were the young that were hatched from eggs collected by the National Center for Stock Enhancement of Kyoto Fisheries Promotion Foundation and that were bred at the center. The red sea breams and prawns used in the test were young ones that were hatched from eggs collected by Shizuoka Warm Water Utilization Center and that were bred at the center.

The undiluted test liquid was prepared immediately after kneading of the CaO-improved soil in accordance with JIS K 0058-1: Methods for Testing Chemical Substances in Slags—Part 1: Method of Testing Amounts of Elution. First, the CaO-improved soil was put into a solvent (filtered seawater) in a volume ratio of 1:10. Next the solution was stirred at about 200 rpm for six hours and then left for 10 to 30 minutes. After that, the supernatant liquid was left for 18 to 24 hours to cause suspensoids to precipitate. The liquid removed from the suspensoids was used as the undiluted test liquid. The test liquids were obtained by diluting the undiluted test liquid by adding filtered seawater heated previously to about 20°C. The

Table 2 Relationship between cumulative number and ratio of death and water consistency of pH

Consistency of pH	Duration time (hour)							
(%)	0	1	3	6	24	48	72	96
0	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
7.7	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
14.6	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
27.7	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
52.6	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
100	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
52.6 (adjust pH area)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)
100	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)	0/10 (0)

* Denominator is number of sample, numerator is cumulative number of death.

other test conditions are shown below.

Exposure method: 96 hours of exposure by the semi-static method (all water changed every 24 hours).

Test vessel and liquid volume: 57L glass water tank (test liquid volume: 40L).

Number of subjects: 10/concentration.

Test liquid: Oxygen saturation kept at 60% or more; water temperature 20 ± 1°C; salt 30% to 35%.

Lighting: Fluorescent lamp 14 hours ON/10 hours OFF.

Feeding: Not done.

In order to lighten the burden of separating the individual subjects, each subject was kept in a cubic basket made of stainless steel wire (each side about 20 cm, mesh 5.5 mm), which had a glass cover (each side about 24 cm, thickness about 0.3 cm) on top, was sunk into a water tank filled with the test liquid. In addition, to enable the subject to hide itself in its basket, a stainless steel sheet (about 20 cm × 13 cm) was set obliquely in the basket.

As a representative example of the test results, **Table 2** shows the cumulative numbers of deaths and the cumulative rates of deaths of samples (black abalones) with the lapse of time. At the end of the test, no deaths were found in any test zone. From the test results shown, we considered that the median lethal concentration (LC50) of CaO-improved soil for black abalones was higher than the concentration of the undiluted test liquid. Similar results were obtained with the red sea breams and prawns. Thus, the safety of CaO-improved soil for the marine life could be confirmed.

3. Turbidity Restraining Effect

3.1 Effect to restrain turbidity during Input of soil

When soft dredged soil is mixed with CaO improver, it immediately increases in strength (viscosity) due to the water absorbing reaction of CaO. Thus, it is considered that the CaO-improved soil hardly causes water to become turbid even when it is kept into the water immediately after it is prepared. With the aim of verifying the

Table 3 Physical properties of dredged soil and steelmaking slag [2)]

	Soil density (g/cm^3)	Wet density (g/cm^3)	Surface dry density (g/cm^3)	Grain size distribution (%)				Water content (%)
				Gravel	Sand	Silt	Clay	
Dredged soil	2.685	1.320	-	-	-	-	-	154.2
Steelmaking slag	3.269	-	2.995	68.6	25.9	5.5		-

turbidity restraining effect of CaO improver, we performed an experiment using a water tank.

The properties of CaO improver and dredged soil used in the test are shown in **Table 3** [2)]. The CaO improver was equivalent in grain size distribution to CS-20 specified in JIS A 5015. The dredged soil was collected from the Bay of Tokyo.

The experiment was performed indoors by using a water tank with an open top as shown in **Photo 1** [2)]. One minute after the sample was put into the water tank from the open top, the condition of the water in the tank was photographed, and the RGB values of the photographic image were converted in terms of the water turbidity to calculate the total turbidity. Note that using a turbidity meter installed in the water tank, we confirmed beforehand that there was a correlation between the RGB values of photographic image and the measured turbidity of water. The experimental results are shown in **Table 4** [2)]. Dredged soil and CaO-improved soil were subjected to the experiment. Based on the results of our preliminary study,[3)] we decided that the mixing ratio of CaO improver should be 30vol%. The falling velocity of sediment was also measured. As a result, it was found that the falling velocity of sediment of CaO-improved soil was higher than that of the dredged soil proper, 0.83 m/s vs. 0.49 m/s.

The reason for that is probably that the wet density of the CaO-improved soil (1.71 g/cm^3) was higher than that of the dredged soil proper (1.32 g/cm^3). However, the separation or breakdown of soil lumps due to the increase in soil resistance in the water was not observed at all. The turbidity per unit amount of soil input during the fall of soil particles was calculated. As a result, it was confirmed that the turbidity with the CaO-improved soil was 1.38 g/m/kg-wet, or about 30% of the turbidity with the dredged soil (5.29 g/m/kg-wet). This is considered due to the fact that the viscosity of the CaO-improved soil was higher than that of the dredged soil proper, 8.8 cm vs. 14.3 cm obtained by a cylinder flow test performed before soil input to the water. Namely, it is considered that the CaO-improved soil was less susceptible to the separation and breakdown of soil lumps. The turbidity of the water after the fall of soil particles was also calculated. The calculated water turbidity was 0.60 g/kg-wet for the CaO-improved soil and 2.16 g/kg-wet for the dredged soil proper. Thus, the former was about 30% of the latter as in the case mentioned above. As a result, the total water turbidity (= turbidity during fall of soil particles + turbidity after fall of soil particles) was 24.8 g for the dredged soil and 6.7 g, or about 30%, for the CaO-improved soil.

3.2 Effect to restrain input soil from rolling up

After solidification, the CaO-improved soil shows better resistance to wave force than dredged soil proper. However, the soil does not solidify immediately when it is put into the water. It was therefore considered that the soil in the water might be rolled up by the wave force, causing the water to become turbid. Therefore, we performed an experiment for verification using an ocean environment simulator that is capable of generating waves.

In the experiment, two types of soil were tested—dredged soil and CaO-improved soil (CaO improver volume ratio: 30%). In order to eliminate the difference in hardness between the soil samples, the CaO-improved soil was added with water to make its flow value right after mixing become the same as the flow value (11 cm) of the dredged soil.

Each of two 10 L (336 mm × 194 mm × 156 mm) containers,

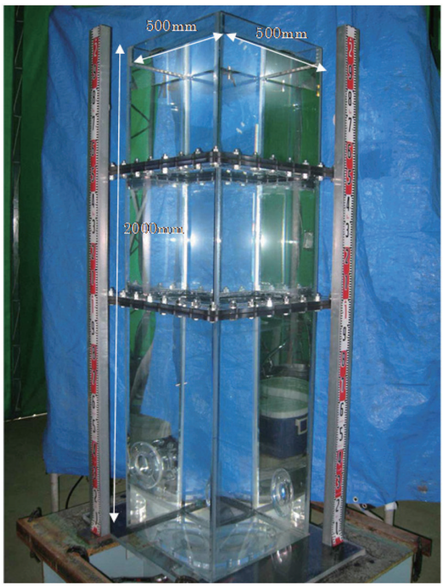
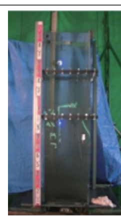


Photo 1 Water tank for turbidity experiment [2)]

Table 4 Result of turbidity experiment by water tank [2)]

		Dredged soil	CaO-improved soil
Slag volume ratio		0%	30%
Cylinder flow (cm)		14.3	8.8
Wet density (g/cm^3)		1.32	1.71
Situation of test			
Velocity of fall (m/s)		0.49	0.83
Unit turbidity	Turbidity of falling (g/m/kg-wet)	5.29	1.38
	Turbidity of after falling (g/kg-wet)	2.16	0.60
Total turbidity (g)		24.8	6.7

one filled with dredged soil and the other filled with CaO-improved soil, was installed in an ocean environment simulator. The depth of water (seawater collected from Tokyo Bay) in each simulator was 300 mm. The wave generation conditions were as follows: wave height 1.5 cm and period 2s. The waves were generated for a maximum of 18 hours, during which the turbidity of the water was measured. The outline of the experiment is shown in **Fig. 1**.

Photo 2 shows the condition of each of the soil samples (dredged soil and CaO-improved soil) rolled up by the waves. The change in water turbidity with the lapse of time is shown in **Fig. 2**.

With the dredged soil, the water became very turbid in about 10 minutes after start of the experiment. By the end of the 18-hour experiment, the dredged soil in the 10 L container decreased to nearly half its volume. In the case of the CaO-improved soil, although the water became slightly turbid immediately after start of the experiment, the soil increased in hardness with the lapse of time and the water turbidity almost disappeared by the end of the experiment (18 hours later).

From the above experimental results, we consider that by utilizing the CaO-improved soil, it is possible to execute offshore engineering works without causing the water to become very turbid even in sea areas where the tremie or turbidity preventive membrane (frame) can hardly be used.

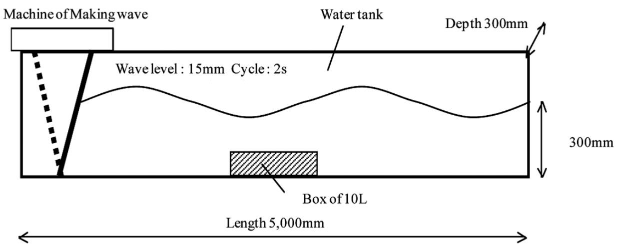


Fig. 1 Image of experiment

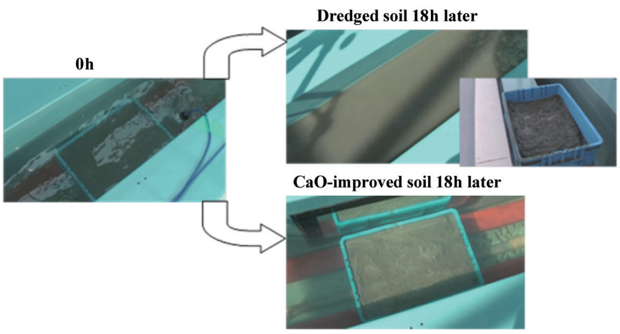


Photo 2 Situation of experiment of turbidity

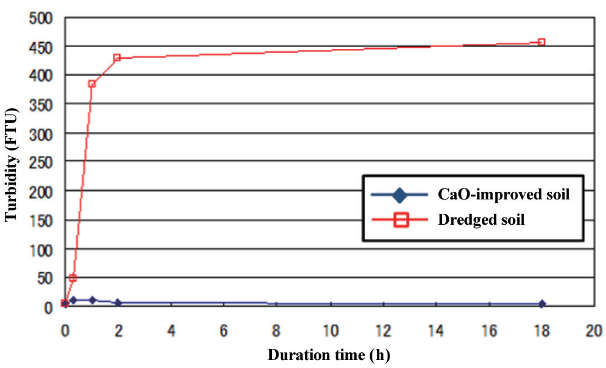


Fig. 2 Relationship between turbidity and duration time

4. Example of Shoal Construction Work in Actual Sea Area

In the shoal construction work offshore the west revetment of Kimitsu Works of Nippon Steel & Sumitomo Metal Corporation (June–July 2011), CaO-improved soil was put into an undersea basin. **Figure 3** [3] shows a longitudinal cross section of the work site. The shoal (area: 70 m × 160 m) was constructed as follows.

First, a dike of solid hydrate was built around the basin. Next, CaO-improved soil was put into the basin. Finally, the top of the CaO-improved soil was covered with pit sand and the iron supply unit (Vivary™ Rock). The CaO-improved soil was prepared by mixing CaO improver in soil using a large backhoe in an open-deck soil carrier (**Photo 3** [3]) and put directly into the basin where the maximum water depth was about 10 m. The quantity of CaO-improved soil prepared and put into the basin was 15 200 m^3.

During execution of the work, several points of observation were installed in a circle 100 m in radius around the point of soil input as shown in **Fig. 4** [2] to measure with a multifunction water quality meter the concentration of suspended solids (SS) in the direction of depth from the surface to the bottom of the sea. The measurement results are shown in **Table 5** [2]. As in the case of the experiment using water tanks, dredged soil and CaO-improved soil (CaO improver volume ratio: 30%) were input. The cylinder flow value before input was 14.3 cm for the dredged soil and 8.7 cm for the CaO-improved soil, both being nearly the same as in the experiment using water tanks. The water turbidity was measured for 70 minutes from the time the soil was put into the sea, and plans of turbidity distribution for the input soils were prepared with consideration given to their distribution and amount in horizontal and vertical directions.

Looking at the turbidity distribution right after soil input, it can be seen that the turbidity caused by the CaO-improved soil is generally less conspicuous than that caused by the dredged soil. A similar phenomenon was observed in the experiment using water tanks.

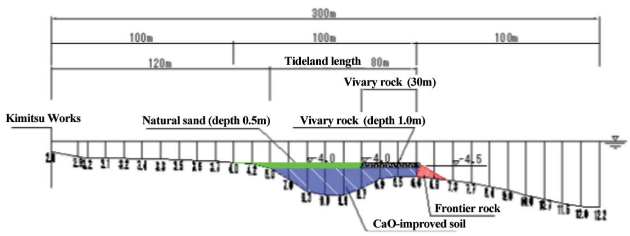


Fig. 3 Tideland cross section [3]

(a) Situation of mixing (b) Situation of putting in the sea

Photo 3 Situarion of construction [3]

Overall, it can also be seen that the turbidity caused by the dredged soil and CaO-improved soil decreases with the lapse of time, although the turbidity caused by the CaO-improved soil disappears earlier. This is considered because the CaO-improved soil has higher density as shown in Table 3 and hence it precipitates faster. From the SS concentrations measured for 70 minutes after soil input, the total amount of turbidity was calculated by using the following equation and was defined as the unit turbidity.

Total amount of turbidity (g) = [Turbidity at each observation point & each water depth zone (g/m^3) × Flow velocity in direction perpendicular to cross section (m/s) × Cross-section area of each observation point & each depth zone (m^2) × Observation time (s)] (1)

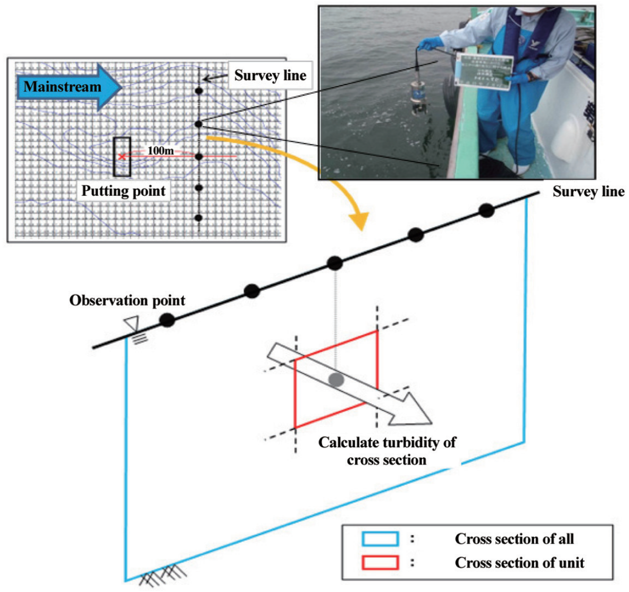


Fig. 4 Observation method of turbidity in site [2]

The calculated unit turbidity was 21.2 × 10^{-3} t/m^3 for the dredged soil and 6.7 × 10^{-3} t/m^3 for the CaO-improved soil, the latter being about 30% of the former.

5. Examples of Monitoring after Work Execution

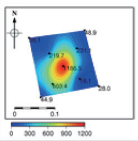
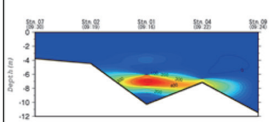
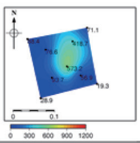
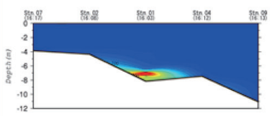
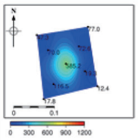
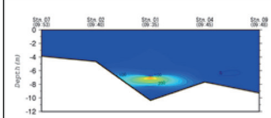
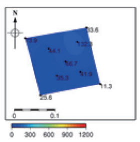
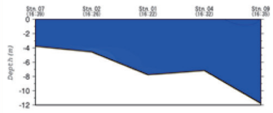
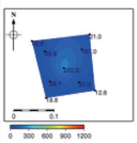
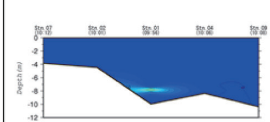
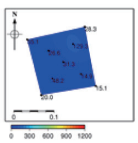
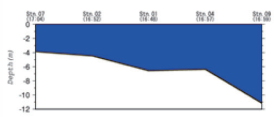
5.1 Monitoring of water quality

Since construction of the shoal, the qualities of water and the conditions of growth of seaweeds and other marine life in the shoal and its neighborhood have been monitored periodically. For the purpose of the monitoring, the shoal constructed was designated as the experimental zone (S2) and a point 300 m away from the experimental zone along the revetment was selected as the object zone (T2). The object zone had a water depth of about 6 m and was similar in many respects to the experimental zone before execution of the work. Therefore, it was considered that the differences made by construction of the shoal could be measured by comparing S2 with T2. **Figure 5** [4] shows the results of measurement of dissolved oxygen concentrations obtained in September 2011. When the dissolved oxygen concentration is less than 2.0 mg/l, it is called an oxygen-deficient condition. It is said that the shorter the duration of oxygen-deficient condition, the better is the living environment for marine life. The oxygen-deficient condition lasts shorter in S2 than in T2, indicating that refilling the deep-cut basin with CaO-improved soil solved the problem of oxygen deficiency in S2.

5.2 Monitoring of marine life

Seaweeds were transplanted in the constructed shoal in October 2011 and the condition of growth of those seaweeds and other marine life was investigated in August 2012. **Photo 4** [4] shows representative examples of the observed marine life. It has been confirmed that the shoal is transforming itself to a good seaweed-growing and fishing ground, offering a bright prospect to the fishermen in the locality. We intend to continue monitoring the site in the years ahead.

Table 5 Turbidity of putting in the sea [2]

	Dredged soil		CaO improved soil	
	Plan	Cross section	Plan	Cross section
1 minutes later				
30 minutes later				
60 minutes later				
Unit turbidity (t/m^3)	21.2 × 10^{-3}		6.7 × 10^{-3}	

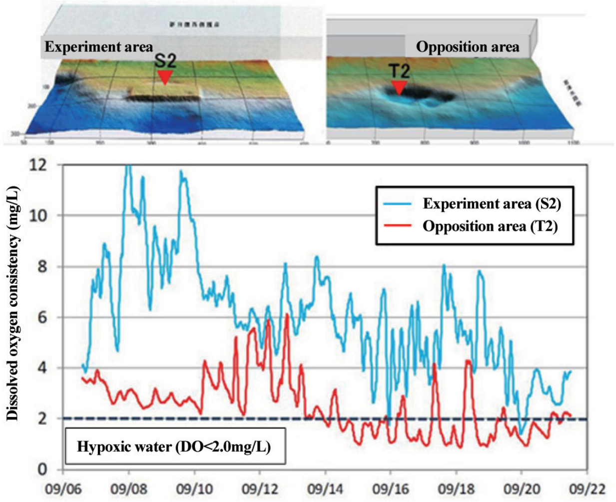


Fig. 5 Dissolved oxygen consistency in experiment area and opposition area [4)]

6. Conclusion

Concerning the usefulness of CaO-improved soil as a material in construction of shoals, the following facts were found.

1) The CaO-improved soil is safe in terms of the elution of heavy metals and substances that are hazardous to living things.
2) Using CaO-improved dredged soil, it is possible to reduce the turbidity of water at the time of soil input to about 30% of the turbidity when unimproved dredged soil is used.
3) Using CaO-improved dredged soil, it is possible to restrain the soil particles from being rolled up by the waves when the soil is put into water.
4) By refilling a deep-cut basin in the sea with CaO-improved soil, it is possible to dissolve the problem of oxygen deficiency there.
5) By constructing a shoal using CaO-improved soil, it is possible to create a good seaweed-growing and fishing ground.

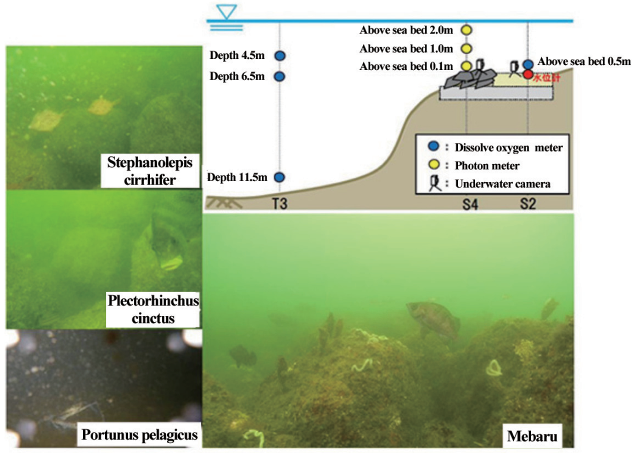


Photo 4 Fishes in experiment area [4)]

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