LOWLAND TECHNOLOGY INTERNATIONAL Vol. 16, No. 2, 89-102, December 2014
International Association of Lowland Technology (IALT), ISSN 1344-9656

DEVELOPMENT OF GROUND ENVIRONMENT IMPROVEMENT AND RESTORATION USING THE ROTARY CRUSHING AND DIFFUSIVE MIXING METHOD AS WELL AS ION ADSORPTION METHOD

Mutsuhiro Ohno [1], Noriaki Nakajima [2], Hideo Suhara [2], Yuichiro Mishima [3] and Hiroyuki Araki [4]

ABSTRACT: Lowlands are easily concentrated by effects of water and soil pollution. There is a demand for the development of technology that can both restore the ground environment and improve soft ground. The authors implemented testing used a rotary crushing and diffusive mixing (referred to hereafter as RCDM) method and an ion adsorption method (Nano-size inorganic Layered Double Hydroxide - NLDH - method) for the purpose of developing technology that can restore the ground environment and improve soft ground. These examples are believed to show the broad applicability of both methods.

Keywords: Rotary crushing and diffusive mixing method (RCDM), Ze, NLDH, ground environment, soil and groundwater pollution, hybrid adsorbent.

INTRODUCTION

Because of the topographical environment, lowlands are easily damaged by flooding, water exposure, ground settlement, earthquakes, tsunamis, etc., and the effects of water, soil pollution, and such are said to be easily concentrated. Furthermore, in the lowlands of the Ariake coastal area, there is a demand for the development of technology that can both restore the ground environment and improve soft ground.

The authors have been conducting development researches on ground improvement by using a rotating crushing and diffusive mixing method (RCDM) and on an ion adsorption technology from the viewpoint of environmental conservation.

New testing results in the Ariake coastal area related to restoration of the ground environment and improvement of soft ground are obtained. In this paper, examples of test application and actual implementation are reported.

At first, some applications of RCDM to common various problems of soft ground on lowlands are shown. Then secondary, some test applications of the ion adsorption technology and/or RCDM to a removal of hazardous heavy metals from naturally polluted ground are reported.

Here, the main methods used in testing are a rotary crushing and diffusive mixing method and an ion adsorption method (Nano-size inorganic Layered Double Hydroxide - NLDH - method). The reported five cases are listed below:

(1) Application of sticky fine clay called “*gatado*” in earth fill for embankments.

(2) Application of dredged soil in embankment material. (quoted from The Japanese Geotechnical Society 2011)

(3) Application in cohesive soil containing underground stems of reeds. (quoted from Kadowaki et al. 2011)

(4) Application in material deposited by tsunamis. (quoted from Suhara et al. 2012)

(5) Application of technology to restore ground polluted by naturally derived and other types of heavy metals.

PRINCIPLE BEHIND ROTARY CRUSHING AND DIFFUSIVE MIXING METHOD

The rotary crushing and diffusive mixing method (Suhara et al. 2007) is a new method that enables crushing and fine grain formation of ground material and homogenous mixing of that material with added

---

[1] IALT member, Graduate School of Science and Engineering, Saga University, Saga 840-8502, JAPAN
[2] JDC Corporation, Akasaka 4-9-9, Minatoku, Tokyo, 107-8566, JAPAN
[3] IALT member, Graduate School of Science and Engineering, Saga University, Saga 840-8502, JAPAN
[4] IALT member, Institute of Lowland and Marine Research, Saga University, Saga 840-8502, JAPAN
Note: Discussion on this paper is open until June 2015

materials. The crushing and mixing thereof are achieved by a striking force and torque generated through high speed rotation (0-1,000 rpm) through a motor drive of multiple flexible chains that rotate at high speeds inside a mixing chamber (cylindrical). As characteristics thereof, this method not only excels in extremely high mixing performance, but can also simultaneously crush and mix all soil types, including sand, cohesive soil, and even rock masses.

Moreover, when ground material and added materials are passed through this device, large amounts of air are introduced by the crushing and diffusive mixing action, and the material is output as a composite soil that has been very homogenously mixed. In addition, because of the uniform presence of air in the voids, this composite soil behaves like sandy soil even if the raw material is a cohesive soil, and thus the material is very easy to handle. The configuration within the mixing chamber (motionless state and operating state) is shown in Photo 1, and the condition of cohesive soil and lime after crushing and diffusive mixing is shown in Photo 2.

Table 1 shows the natural water content and the amount of calcium for a case in which the dehydrated cake of construction sludge is crushed and diffusively mixed with 5% ordinary Portland cement in a mixing chamber with a diameter of φ1,500mm, a rotational speed of 800 rpm, a number of chain increments of 3, a number of chains of 12, and a production volume per hour of 30 m^3/hr.

This sample was obtained by sampling nine equal parts of the cement composite soil (addition of cement 5wt%) output from the belt conveyor in a conical shape.

Table 2 shows variation coefficients of uniaxial compressive strength for other ground improvement method.

The variation coefficients for the natural water content and calcium content have a very small variation, thereby indicating the superiority of the mixing performance of this method, which is shown in Table 1.

As shown in Table 2, it is obvious that 6.7% of the variation coefficient of RCDM shows much advantage against other ground improvement methods.

This result means that RCDM will contribute to the adsorbent (NLDH) reduction because of well mixing of NLDH with soil.

NANO-SIZE INORGANIC LAYERD DOUBLE HYDROXIDE (NLDH) METHOD

Nano-size hydrotalcite substances (NLDH) are a type of Mg-Al based layered double hydroxides (LDHs) with significantly improved anionic absorption performance achieved by adjusting the crystallite size to approximately 10 nm. NLDH substances cover a wide range of pH values (pH 3-11) and are a high

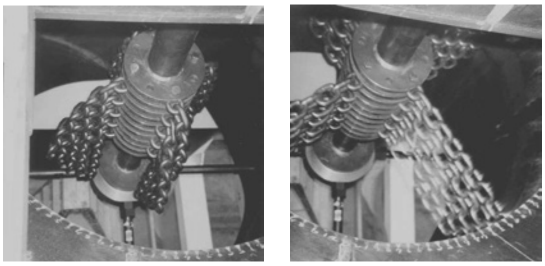

Photo 1 Inner view (Stoical & Operating States)

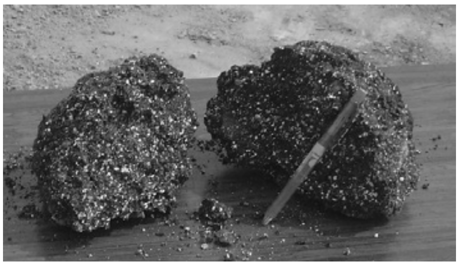

Photo 2 Clay soil and lime (after treatment condition)

Table 1 Mixing ability of rotary crushing and diffusive mixing method

Test piece (No.)	1	2	3	4	5	6	7	8	9	Average (%)	Standard Deviation (%)	Coefficient of Variation (%)
Natural Moist Content W_n (%)	72.1	70.2	70.3	69.1	68.4	66.7	67.3	69.0	69.3	69.2	1.626	2.4
Calcium (%)	6.48	6.70	6.50	6.73	5.61	6.24	5.95	6.41	6.23	6.32	0.36	5.7

Table 2 Variation coefficients of uniaxial compressive strength

method	variation coefficients(%)	Number of sample	Source
The rotary crushing and diffusive mixing method	6.7	5	#1
Tube mixing method	28.4	37	#2
Fluidization treatment method	19.1	86	#3

#1 6th International Symposium of resources circulation production system " case study published collection"
#2 The ground improvement symposium by cement solidifying material
#3 Ground improvement design guidelines for building foundation

performance anion adsorbent that can adsorb anions of fluorine, boron, hexavalent chromium, and the like with good efficiency (Ohno et al. 2010). Examples of applications thereof include use in the treatment of industrial wastewater, in the purification of polluted soil and groundwater, in the treatment of leachate from waste disposal sites, in the recovering phosphorus from sewage, (Mishima et al. 2013), and the like.

Hydrotalcite substances have been conventionally known to exhibit anion exchange performance, but the exchange performance of commercially available products is low, and industrial use as an ion adsorbent was thought to be difficult. This is because hydrotalcites that have been commercially available in the past have a crystallite size of at least 30 nm, which is large, and have a property of selectively capturing and securing carbonate ions between the layers. Thus, when carbonate ions are captured in large numbers in the manufacturing stage or during storage, exchange with ions such as boron with relatively low selectivity becomes difficult, and as a result, the anion adsorption performance is thought to decrease significantly.

On the other hand, as the NLDH of this technology has a small crystallite size of 10 nm or less, carbonate ion selectivity is weak due to the property of the broken bonds of the edge face being superior to the interlayer ion-exchange property, and anions are strongly captured between the layers. As a result, it is believed that interlayer ions can be exchanged with boron and other anions without selectivity, and anion adsorption performance can be improved. The NLDH of this technology is an inorganic anion-exchange material that achieves a nano-level crystallite size by manipulating the synthesis process for the layered double hydroxide (generally called LDH) and successfully improves the anion adsorption performance (see Fig. 1). The crystallite size of the NLDH is determined by Scherrer's equation (1) from the results of X-ray diffraction.

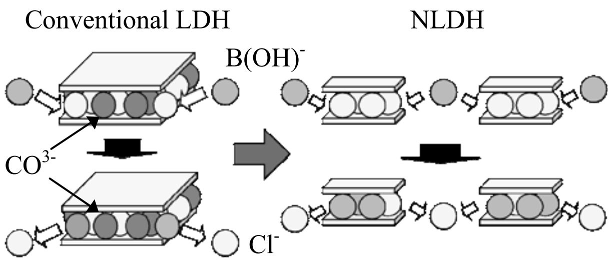

Fig. 1 Image of anion absorption by LDH and NLDH

Table 3 Crystallite size

Standard Sample	MICA	Si
Existing HTP	35.8	31.2
Conventional	23.3	22.8
NLDH	9.1	9.2

NLDH is determined by Scherrer's equation from X-ray diffraction.

$$\text{Crystallite size } \varepsilon = \frac{\lambda}{\beta \cos\theta} \tag{1}$$

λ: Measured X-ray wavelength (Å)
β: Spread of the diffraction line according to the size of the crystallite (rad)
θ: Bragg angle of the diffraction line

The crystallite sizes resulting from a compensation of β using the NIST (U. S. National Institute of Standards and Technology) standard samples for synthetic mica and metal silicon are shown in Table 3. The top row shows figures for an existing hydrotalcite product, the middle row shows figures for a conventional hydrotalcite product, and the bottom row shows figures for NLDH.

A crystallite size of 10 nm or less was confirmed from the measurement results for both standard samples. NLDS can be processed in a variety of forms according to the application, with examples including a slurry form, a dehydrated cake form, a powdered form, a granular form, etc. The density of NLDH is 2.28g/cm^3, the average value of the particle size is 16.202 μm, 50%D is 21.796 μm.

To confirm the basic performance of powdered NLDH, 1.0 wt% of powdered NLDH was added to a standard solution, and an adsorption test was implemented. The results are shown in Fig.2. Figure 3 shows the pH dependence of the adsorption performance

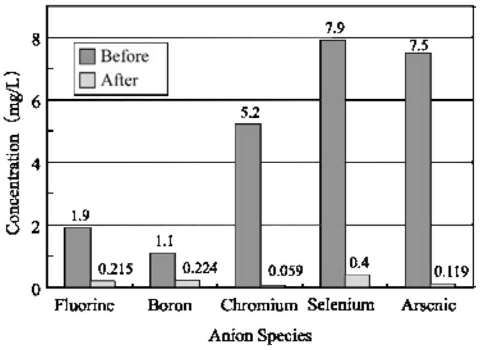

Fig. 2 Result of adsorption test for each heavy metal

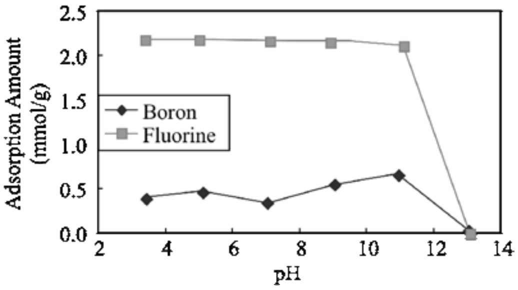

Fig. 3 pH dependance of the adsorption performance of NLDH of NLDH for boron and fluorine. From the figure, we can see that there is no decrease in the adsorption strength of NLDH in the pH range of 3 to 11. Thus, NLDH exhibits stable adsorption performance in a wide range. Moreover, NLDH has the ability to adsorb some cations due to the broken bonds of the edge face. Note that currently, the authors are developing a hybrid ion adsorption material HB-Ze/NLDH (referred to hereafter as HB-Ze/NLDH) that can simultaneously adsorb anions and cations through a technique of phosphorous recovery using NLDH and artificial zeolite and by simultaneously synthesizing NLDH and artificial zeolite. (Mishima et al. 2013)

Regarding the performance of HB-Ze/NLDH, testing results using a prototype HB-Ze/NLDH product and testing results using NLDH are shown in the last section for a case in which the products were applied to actual polluted soil and groundwater.

APPLICATION OF STICKY FINE CLAY CALLED “GATADO“ IN EARTH FILL FOR EMBANKMENTS

Experiments were conducted by using the the rotary crushing and diffusive mixing method to test the applicability in earth fill for embankments using gatado sticky fine clay excavated in a river works project along the coast of the Ariake Sea (see Photo 3). The results thereof are reported here.

First, the target quality was determined by the appropriate range for levee body materials. More specifically, a range was targeted to the River Earthwork Manual, the Japan Institute of Country-ology and Engineering, that satisfied a fine grain fraction content rate of 15% ≤ Fc ≤ 50% between the upper limit for the dangerous range for cracks and the lower limit for impermeable materials. The target grain size range that satisfies the above conditions is shown in Fig.4.

In the execution of the testing, gatado fine clay and gravel were crushed in advance and appropriately blended as a levee body material with reference to the combined grain size of the gatado fine clay and gravel in accordance with the 9 formulation ratios shown in Fig.5. Then, a crushing and diffusive mixing test was conducted with an assumed formulation ratio of gatado:gravel = 1:2.7.

The testing was conducted using riverbed gravel and temporarily placed gatado fine clay as shown in Photo 3. The gatado fine clay used in the testing is shown in Photo 4, and the riverbed gravel is shown in Photo 5. The improved soil that was obtained after crushing and diffusive mixing of the material blended at a ratio of gatado:gravel = 1:2.7, which was determined based on the combined grain size of the crushed material obtained by crushing each of the materials in advance, and is shown in Photo 6.

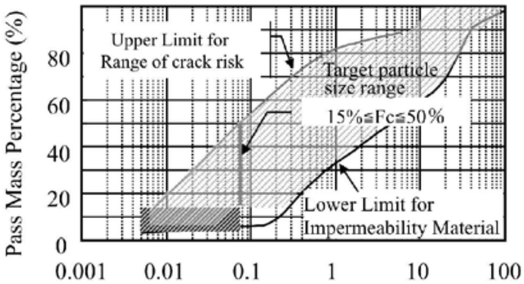

Fig. 4 Target range of granularity

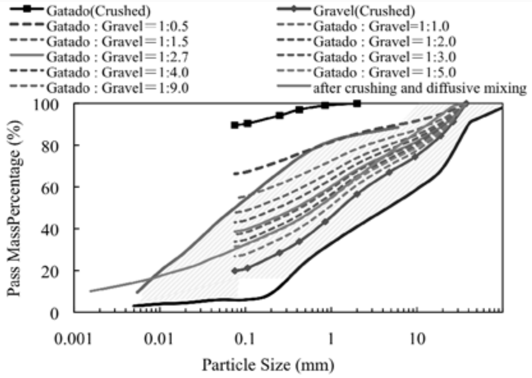

Fig. 5 Test result’s granularity after crushing and diffusive mixing

Photo 3 *Gatado* at temporary stock yard

Photo 4 *Gatado* – used as testing materials

Photo 5 Riverbed gravel – used as testing materials

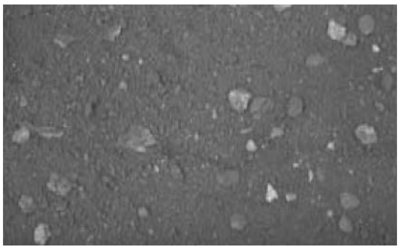

Photo 6 Improved soil - after mix *Gatado* : Gravel = 1 : 2.7

The crushing and diffusive mixing test results are as follows. The grain size distribution obtained after crushing and diffusive mixing is shown in Fig.5, and the soil quality test results are shown in Table 4. Based on these test results, at a grain size of 0.008 mm or less, the data falls within the range of a “crack risk,” but at most grain size ranges, the target grain size range is achieved. If the gatado fine clay and gravel are blended at a ratio of 1:2.7 respectively, the mixture is thought to be appropriate as a levee body material.

Moreover, the cone index was 650 kN/m^2, which is above the 400 kN/m^2 (Waste soil use criteria, Ministry

Table 4 Test Result of soil investigation for *Gatado* and Gravel

Investigation Items				*Gatado*		Gravel		Crush & Mixed *Gatado* : Gravel = 1 : 2.7	
Physical Characteristics	Density of Particle ρ_s (g/m^3)			2.572		2.678		2.660	
	Natural Water Content w_n(%)			65.9		10.5		23.3	
	Particle Size	Maximum Particle Size D_{max}(mm)		2.00		75.0		37.5	
		Stone (> 75mm)	Course Stone (75-300mm)	0.0		0.0		0.0	
		Gravel (2.00-75mm) (%)	Course Gravel (19.0-75mm) (%)	0.0	0.0	30.0	49.0	6.0	35.0
			Middle Grain Gravel (4.75-19.0mm) (%)	0.0		10.0		18.0	
			Fine Grain Gravel (2.00-4.75mm) (%)	0.0		9.0		11.0	
		Sand (0.075-2.00mm) (%)	Course Sand (0.850-2.00mm) (%)	1.0	13.0	13.0	35.0	12.0	35.0
			Middle Grain Sand (0.250-0.850mm) (%)	6.0		10.0		13.0	
			Fine Sand (0.075-0.250mm) (%)	6.0		8.0		10.0	
		Fine Particle Fraction (<0.075 mm) (%)	Silt (0.005-0.075mm) (%)	44.0	87.0	10.0	16.0	16.0	0.0
			Clay (< 0.005mm) (%)	43.0		6.0		14.0	
		50% Particle Size D_{50} (mm)		0.01		1.92		0.7	
		20% Particle Size D_{20} (mm)				0.15		0.02	
		Uniformity Coefficient U_c				301.0		938.0	
		Curvature Coefficient U_c'				2.51		2.42	
	Liquid Limit / Plastic Limit of Soil	Liquid Limit ω_L (%)				—		64.8	
		Plastic Limit ω_P (%)				—		30.5	
		Plastic Index I_P				—		34.3	
		Consistency Index^{*3} I_C				—		1.21	
	Ignition Loss	L_i (%)				3.0		4.21	
Chemistry	pH					—		6.8	
Engineering Ground Material Classification	Classification	Classified Name of Ground Material		Sandy Fine - Grained Soil		Fine-Grained Sandy Gravel		Clayey Rudaceous Sand	
		Classified Code		(F-S)		(GFS)		(SCHG)	
Stabilized	Compaction	Maximum Dry Density ρ_{dmax}(g/cm^3)						1.608	
		Optimum Moist Content W_{opt}(%)						20.2	
	Trafficability	Cone Index q_c(kN/m^2)				—		650	
Permeability	Permeability Index	Permeability Index k_{15}(cm/s)(ρ_{dmax}×Dencity 85%)						6.07×10^{-4}	

Assessment	Particle Size	Targetting Range of Particle Size (Adoptable Range of Constraction Material for Dike)	○
		Fine Fracture F_c=15-50%	○
	Cone Index	Available Cone Index for Normal Bulldozar q_c=400kN/m^2	○
		Judgement	○

of Land, Infrastructure, Transport and Tourism） cone index necessary from an execution perspective, and thus no problem exists. Therefore, the applicability of gatado fine clay as earth fill for embankments was confirmed.

APPLICATION OF DREDGED SOIL IN EMBANKMENT MATERIAL

One example of methods for the application of dredged soil in embankment material is a preliminary mixing treatment method. The preliminary mixing treatment method is a method in which dredged soil or another type of sediment is mixed with a small amount of a stabilizing material (cement), and then sprayed with a separation prevention agent to obtain treated soil with improved soil quality. Then, the treated soil is transported and deposited as is to reclaim stable ground. This method is effective at preventing liquefaction, reducing soil pressure, and increasing the bearing capacity, and in results from design and construction work in recent years, there has been an increasing number of cases of the adoption of this method in combination with renewal construction work for piers, seawalls, etc., as a measure to reinforce earthquake resistance with consideration of soil pressure reduction.

Furthermore, implementation cases that reduce costs by effectively utilizing the construction generated soil are quickly becoming prevalent. A method of mixing the sediment and stabilizing material includes a belt conveyor method described in the “Technical Standards for Harbor Civil Works” from the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), and recently, results from the application of new methods (self-propelled soil quality improvement method, rotary crushing and diffusive mixing method, mechanical kneading mixer method) have been increasing. Here, an example of the Tokuyama-Kudamatsu Port is introduced.

Specifically, an example of earthquake reinforcement (soil pressure reduction, liquefaction prevention) of a pier (-10m) using the rotary crushing and diffusive mixing method is introduced. In this case, the rotary crushing and diffusive mixing method was applied to dredged soil and sediment generated from site excavation. A characteristic of this site is the inclusion of a significant amount of rubble (mainly concrete remnants) mixed into the dirt generated at the site, and therefore this method was adopted because it can simultaneously crush the rubble as well and utilize it as soil material.

Note that in the adoption of this method, construction was implemented utilizing an individually specified system (approval for an intermediate treatment facility was necessary for rubble treatment of 5 tons per day or greater). The execution volume was 25,705 m^3, the used machine was a rotary crushing and diffusive mixer (100 m^3/h class), and cement was added at a rate of 12%.

A standard cross-sectional diagram of the execution work is shown in Fig.6, and a panoramic view is shown in Photo 7. In addition, conditions of backfill with a clamshell at a depth of GL-5m or deeper are shown in Photo 8, and conditions of backfill with a backhoe at depths of less than GL-5m are shown in Photo 9.

Note that with check boring after execution, every spot cleared the design uniaxial compression strength of q_u = 300 kN/m^2, and thus good results were obtained. Hence application in embankment material generated at the worksite that also includes dredged soil was confirmed.

APPLICATION IN COHESIVE SOIL CONTAINING UNDERGROUND REED SYTEMS

In this case, testing was conducted as part of various examinations into improving and effectively utilizing high quality embankment soil, and the testing was conducted on cohesive soil containing underground stems of reeds at the Tone River Upstream Work Office of the MLIT.

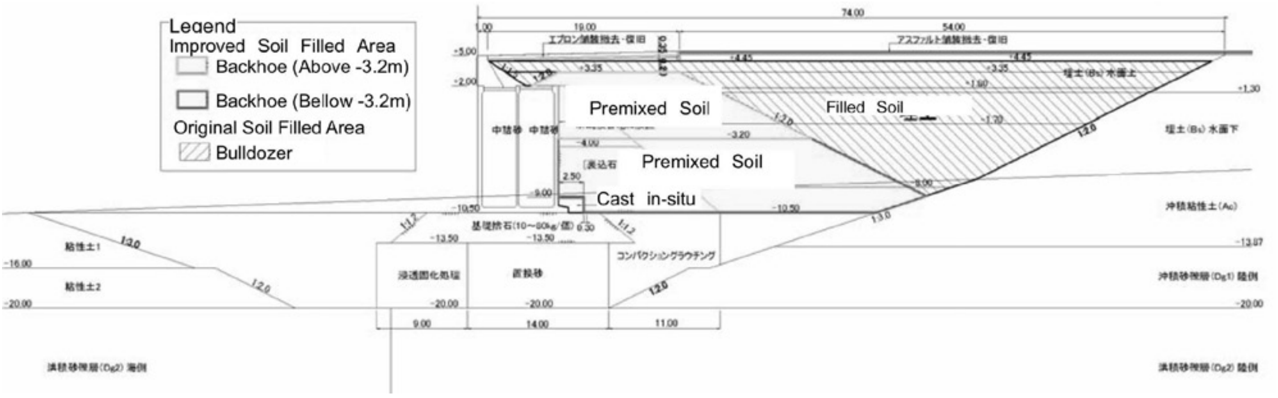

Fig. 6 Typical section for construction

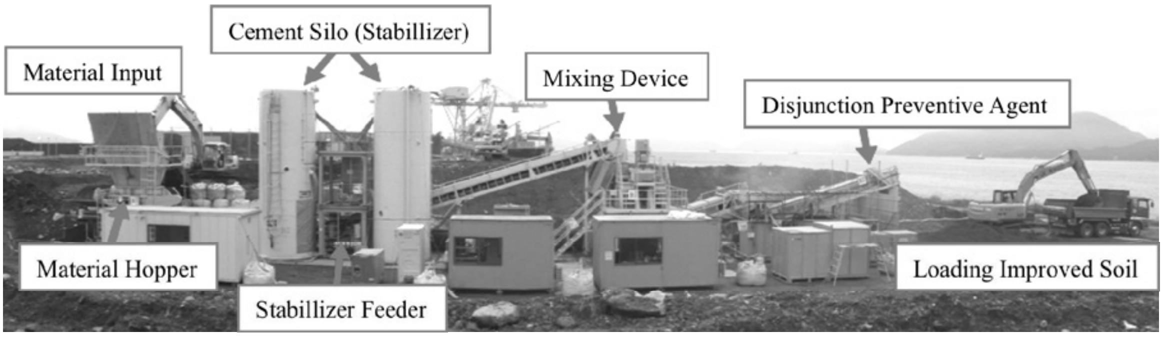

Photo 7 General view for construction equipments


Photo 8 Backfilling by clamshell


Photo 9 Backfilling by backhoe

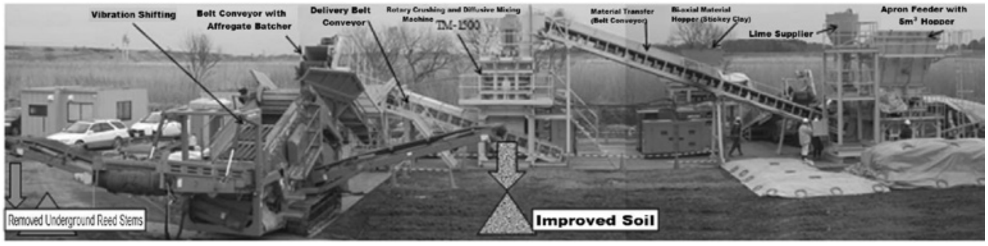

Photo 10 General view for plant equipments


Photo 11 Clumped reed containing soil at temporary stock yard

In order to utilize high water content cohesive soil containing underground reed stems, not only must the soil be finely unraveled to improve the workability, but the underground reed stems and soil must be separated, the underground reed stems must be removed, and the soil must be improved to high quality soil material that exhibits excellent permeation resistance and does not contain organic matter.

This time, the rotary crushing and diffusive mixing method was used for the purpose of shredding soil containing clumped reeds excavated from the planned excavation site and to efficiently remove the large amounts of underground reed stems mixed into the soil and sand. An overview of the results obtained from the execution of on-site testing is reported.

The test was executed at the plant facility shown in Photo 10 for the below-described materials A and B2 collected from the clumped reed containing soil shown in Photo 11.

Material A had a natural water content w_n = 51.5% and a grain fraction ratio of Fc=93.6%, and material B had a natural water content w_n =34.7% and a grain fraction ratio of Fc=59.9%. Crushing, diffusive mixing, and sieve analysis tests were conducted on both material types.

The underground stems removed through sifting material B are shown in Photo 12, and the improved embankment soil is shown in Photo 13. Moreover, the efficiencies at which the underground reed stems were removed from each material are shown in Fig.7.

Good removal efficiency is shown for both materials, and the ability to improve cohesive soil containing underground reed stems to create good quality embankment material that can be effectively utilized was demonstrated.

APPLICATION IN MATERIAL DEPOSITED BY TUNAMIS

A demonstration test as described below was conducted using actual equipment (rotational speed of 750 rpm) in order to confirm whether material deposited by tsunamis that is mixed with rubble can actually be processed appropriately using crushing and diffusive mixing technology and then effectively utilized as embankment material.

An overview of the testing equipment is shown in Fig. 8, and a panoramic view of the testing equipment is shown in Photo 14. In the testing, first, material shown in Photo 15 that was deposited by a tsunami and gathered in Ishinomaki, quicklime shown in Photo 16, or concrete remnants shown in Photo 17, etc., were inserted via a hopper in various mixture proportions as shown below, crushed and diffusively mixed, and then vibration-sifted to separate the material into rubble and improved soil as shown in Photo 18. The rubble included concrete remnants and asphalt remnants. The testing details were as follows.

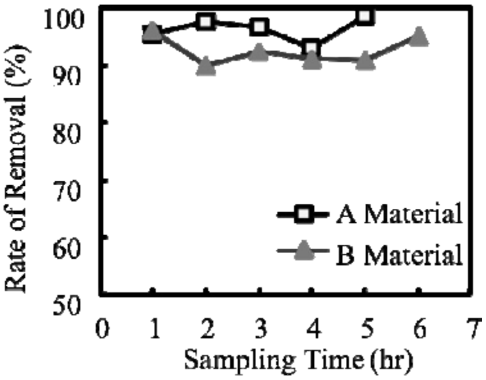

Fig. 7 Removal ration of underground reed stems

Photo 12 Underground stems removed through sifting

Photo 13 Improved embankment soil

Photo 14 Overview of testing plant

Photo 15 Tsunami deposit materials mixed with rubble stone in Ishinomaki

Photo 16 Quicklime (particle size 1～5mm)

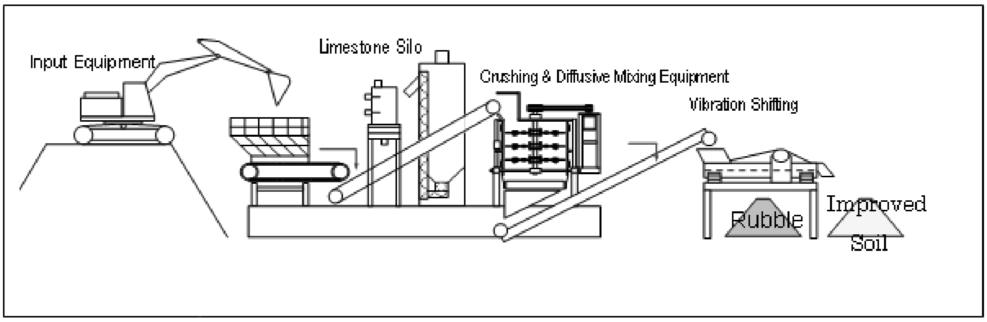

Fig.8 Diagram of testing flow and equipments

1) Separation Testing of Rubble and Soil
   (1) Only 20 mm vibration sifting
   (2) Crushing and diffusive mixing (with addition of 5% quicklime) + vibration sifting
   (3) Crushing and diffusive mixing (mixture with 20% concrete remnants) + vibration sifting

2) Application Testing as Embankment Material
   (1) Physical properties of material deposited by tsunamis
   (2) Crushing test of concrete remnants and asphalt remnants (grain size testing)
   (3) Crushing and diffusive mixing test of materials deposited by tsunamis and concrete remnants (grain size testing, cone index test)
   50% mixture, 100% mixture, and 150% mixture of concrete remnants
   (4) Crushing and diffusive mixing testing of materials deposited by tsunamis and asphalt remnants (grain size testing, cone index test)
   50% mixture, 100% mixture, and 150% mixture of asphalt remnants
   (5) Crushing and diffusive mixing testing of materials deposited by tsunamis and quicklime (cone index test)
   Amount added: 3.3% (50 kg/m^3), 6.7% (100 kg/m^3)

Photo 19 shows the conditions for the rubble and soil (vibration sifting only) output with case 1, and Photo 20 shows the conditions for the rubble and soil (with addition of 5% quicklime) output in case 2. Photo 21 shows the conditions for the rubble and soil (20% mixture of concrete remnants) output in case 3.

For the material deposited by a tsunami that included a 5% addition of quicklime and a mixture of 20% concrete remnants, soil adhered to the rubble was removed by the action of the crushing and diffusive mixing, and the rubble and soil were separated with a high degree of accuracy. In contrast, with only vibration sifting, the rubble that was output had soil adhered to it, and it was determined that the separation of the rubble and soil for this material was difficult.


Photo 17 Concrete remnants in Ishinomaki


Photo 18 Shifted rubble and improved soil

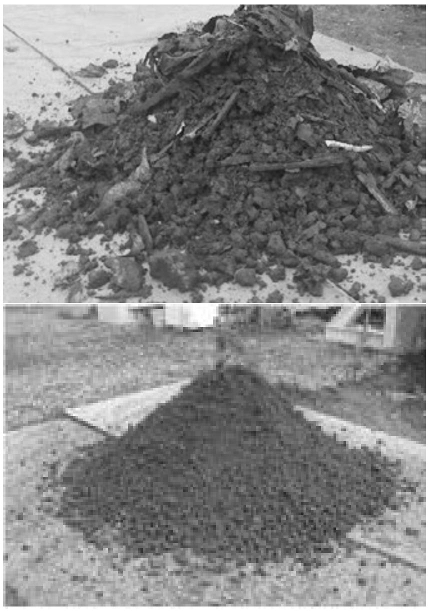
Photo 19 Case 1: rubble and disposed soil (vibration shifting)


Photo 20 Case 2: Rubble and disposed soil (added 5% of quicklime)


Photo 21 Case 3: Rubble and disposed soil (added 20% of concrete remnants)

Table 5 Physical characteristic test result for Tsunami deposits, concrete remnant and asphalt remnant

Items		Used Ground Materials Deposited by a Tsunami (Ishimaki City)	Used Additional Materials Remnants by Quakes (Ishinomaki)	
			Concrete Remnants	Asphalt Remnants
Density of Soil ρs (g/cm^3)		2.634	-	-
Moist Content w (%)		30.5	-	-
Particle Size	Maximum Particle Size Dmax(mm)	53.0	150	150
	Gravel (%)	11.4	100	100
	Sand (%)	61.7	0	0
	Silt (%)	12.4	0	0
	Clay (%)	14.5	0	0
Consistency	Liquid Limit w_L (%)	38.9	-	-
	Plastic Limit w_P (%)	21.7	-	-
	Plasticity Index I_P	17.2	-	-
Chemistry	Ignition Loss L_i (%)	6.6	-	-
	pH	8.1	-	-
Engineering Ground Material Classification		Clayey Sand Containing Gravel	Gravel	Gravel
Classification Code		(SCL-G)	(G)	(G)
Cone Index	Cone Index qc (kN/m^2)	787	-	-
	Wet Density ρ_t (g/cm^3)	1.849	-	-
	Dry Density ρ_d (g/cm^3)	1.417	-	-

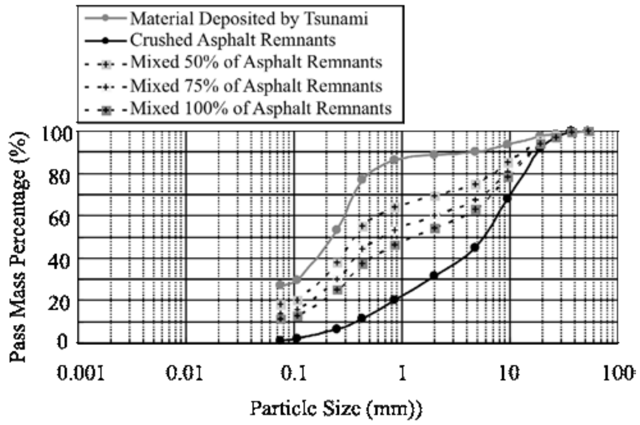

Fig. 9 Test result of crushing test (granularity test) of concrete and asphalt

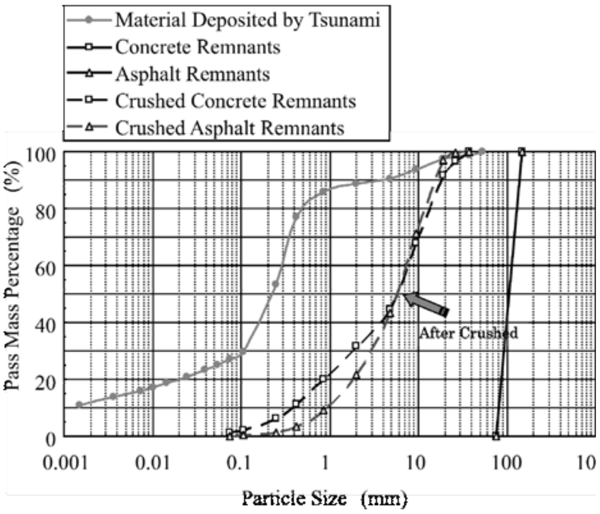

Fig. 10 Test result of crushing test (granularity test) of deposited by tsunamis and concrete after crushing and diffusive mixing

Application testing as embankment material

Table 5 shows the physical properties of the material deposited by a tsunami, the concrete remnants, and the asphalt remnants used in this testing, and Fig.9 shows the results of the crushing test (grain size test) on the concrete and asphalt remnants. As shown, the material that was output had a good grain size distribution.

Moreover, Fig.10 shows grain size testing results for a case in which material deposited by a tsunami was crushed and diffusively mixed with concrete remnants at the three different ratios shown, and Fig.11 shows grain size testing results for a case in which material deposited by a tsunami was crushed and diffusively mixed with asphalt remnants at the three different ratios shown. In both cases, it is believed that the material had the appropriate properties for use as compaction material if estimated from the grain size curves.

Figure 12 shows the cone index for a case in which concrete remnants and asphalt remnants are respectively crushed and diffusively mixed at the three different ratios with material deposited by a tsunami. From Fig.12, it is clear that a cone index of 1,200 kN/m^2 that enables the travel of a dump truck is secured, and thus the mixture ratio (dry weight ratio) of material deposited by a tsunami and remnants becomes 1:0.2, or in other words, a 20% mixture of remnants is good.

Figure 13 shows the cone index after crushing and diffusive mixing for cases in which the addition amount of quicklime was 50 kg/m^3 (addition rate of 3.3%) and 100 kg/m^3 (addition rate of 6.7%). From this figure, it is clear that sufficient strength to secure a cone index of 1,200 kN/m^2 exists with a quicklime addition amount of 50 kg/m^3 (addition rate of 3.3%).

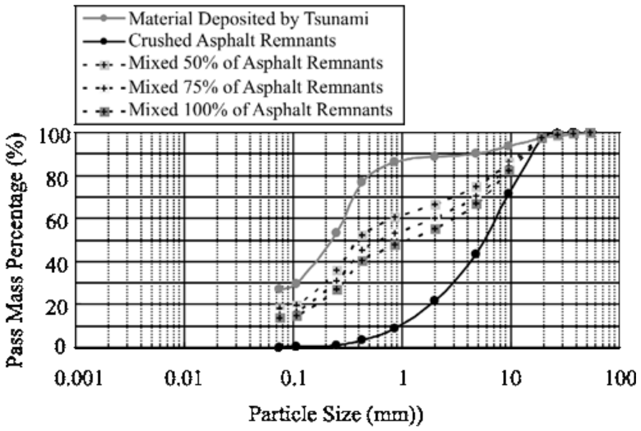

Fig. 11 Test result of crushing test (granularity test) of deposited by tsunamis and asphalt after crushing and diffusive misxing

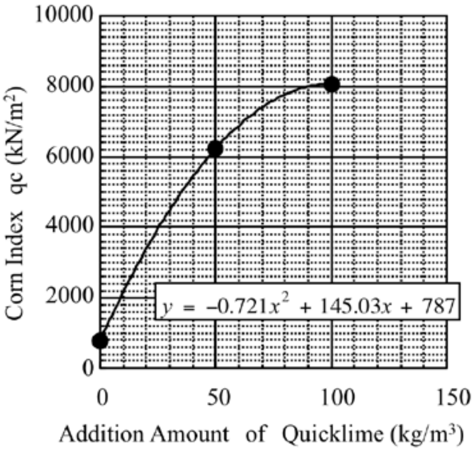

Fig. 13 Relationship of additional amount of quicklime and cone index for crushing and diffusive mixing

Based on the aforementioned results, it is believed that with the application of this method, prescribed embankment strengths can be flexibly supported by changing the amount of quicklime added and the mixture ratio of the remnants with various materials deposited by a tsunami.

APPLICATION OF TECHNOLOGY TO RESTORE GROUND POLLUTED BY NATURALLY DERIVED AND OTHER TYPES OF HEAVY METALS

As described above, the effects of water and soil pollution are said to be easily concentrated in lowlands. The rotary crushing and diffusive mixing method exhibits excellent mixing capability with regards to heavy metal pollutants, and thus application of this method in an insolubilizing treatment method is effective.

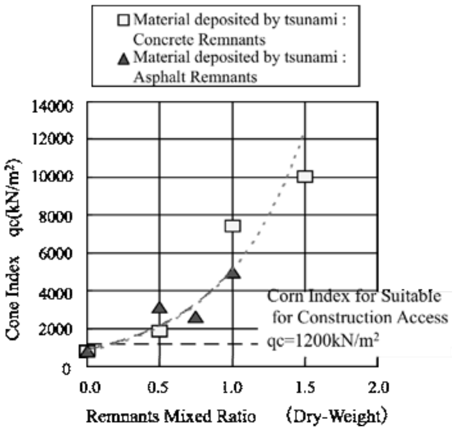

Fig. 12 Corn index for each crushing and diffusive mixing ratio with material deposited by a tsunami / remnants

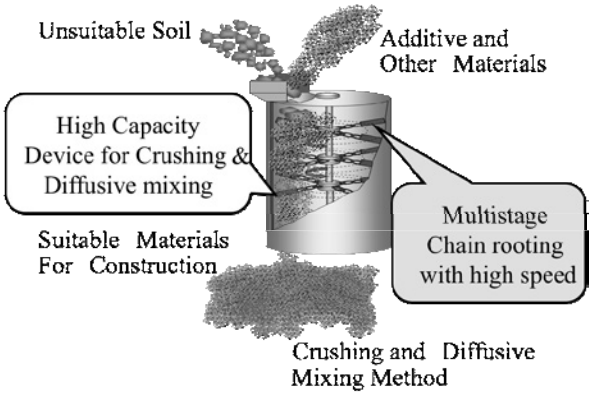

Fig. 14 Principle of technology

In the Soil Contamination Countermeasures Act, the insolubilizing treatment method is recognized as a measure from the viewpoint of preventing the ingestion of groundwater. However, until now, there have not been many cases of execution of insolubilizing treatment because this treatment method is not complete purification, and thus the pollutant content remains, and because a change in ideas that overemphasize excavation and removal, which are behind the April 2010 revisions to the Soil Contamination Countermeasures Act, has not yet become widespread.

However, the insolubilizing treatment method is the basis of the revised Soil Contamination Countermeasures Act, and the frequency of usage of this method as an in-situ countermeasure is increasing. This method also offers merits from a cost perspective because it can be executed at 1/2 to 1/3 the cost when compared to excavation, removal, and replacement with clean soil.

Thus, if this method is adopted with consideration for the risks of groundwater ingestion at each site, it is thought to be an extremely effective method.

Next, regarding soil pollution, the purification of groundwater pollution through column adsorption is possible as an additive (see Fig. 14) of the above-described insolubilizing method (see Photo 22).

A case involving the application (Suhara 2009) of the rotary crushing and diffusive mixing method and a case involving the application of the NLDH method with respect to heavy metal contaminated ground at a factory located in an area along the Ariake Sea and in a reclaimed, lowland of Kitakyushu are described.

For the case involving a factory located in an area along the Ariake Sea, soil and groundwater purification tests were implemented using the rotary crushing and diffusive mixing method, and the NLDH method for soil and groundwater pollution thought to be naturally derived and to have originated from the factory.

The soil and groundwater pollution at this site includes soil contamination from arsenic as shown in Table 6 and composite heavy metal ground water contamination from arsenic, cadmium, lead, and selenium as shown in Table 7. At this site, first insolubilizing tests were conducted using the rotary crushing and diffusive mixing method with NLDH, HB-Ze/NLDH, and commercially available magnesium based insolubilizing agent used as the agent. In this crushing and diffusive mixing method, a ϕ1,000 type mixing tester was used (see Photo 23). Note that the amounts of NLDH, HB-Ze/NLDH, and magnesium based insolubilizing agent that were added were respectively 7% by weight. The test results are shown in Table 6.

For each material, a reduction in concentration was able to be observed, and with HB-Ze/NLDH, the concentrations were reduced to levels at or below the environmental standards. For the other materials as well, it is believed that concentrations below the environmental standards can be achieved by increasing the amount added.

Next, adsorption tests (released metal adsorption tests) were conducted on composite heavy metal ground water contamination from arsenic, cadmium, lead, and selenium with the addition of 1% respectively of NLDH and HB-Ze/NLDH. The test results are shown in Table 7. With both NLDH and HB-Ze/NLDH, good results that were below the environmental standards were achieved.

Table 6 Insolubilzing test result for soil contaminated by arsenic

Name	Arsenic
Stndard Elution Amount	0.01
unit	mg/L
Contaminated Soil	0.37
NLDH - 7%	0.035
HBNLDH - 7%	0.004
Mg based - 7%	0.016

Next, a case in which a magnesium-based insolubilizing agent was used to insolubilize lead contaminated soil at a planned construction site for a rental apartment in a reclaimed, the lowland in Kitakyushu is described.

As part of the execution, treatability tests were conducted in advance using three types of insolubilizing agents. Of those three agents, a magnesium-based insolubilizing agent was selected, and the following types of compositions were determined. For a maximum elution amount of 0.16 mg/L (maximum content of 3,100 mg/kg), the insolubilizing agent addition amount was 6%; for an elution amount up to 0.10 mg/L, the addition amount was 4%; and for an elution amount of up to 0.05 mg/L, the addition amount was 3%.

A panoramic view of the conditions during the execution of the insolubilizing treatment is shown in Photo 24, the conditions at the time that the

Photo 22 Column for adsorption

Photo 23 ϕ 1,000 type Mixing Tester

Table 7 Adsorption test result for combined contaminated ground water by heavy metal

Name	Cadmium	Lead	Arsenic
Standard Elution Amount	0.01	0.01	0.01
unit		ppm	
Contaminated Water	0.0814	0.0126	3.6392
NLDH-1%	0.0016	0.0015	0.0036
HBNLDH-1%	0.0012	Less than Standard Value	


Photo 24 General view of insolubilizing treatment


Photo 25 Insolubilizing agent was added


Photo 25 Output of the improved soil


Photo 27 Backfilling of the insolubilized soil

insolubilizing agent was added are shown in Photo 25, and the output of the improved soil is shown in Photo 26. The improved soil that was output was temporarily placed at a designated site, and every 100 m^3 that passed the official analysis tests was backfilled. Photo 27 shows the backfilling of the insolubilized soil. After execution thereof was completed, the soil was monitored for two years.

The details included measuring the groundwater in an observation well and the amount of elution of soil from a core at a maximum elution amount position. Over the two years period, elution testing was conducted every six months, a total of five times, and it was confirmed that there were no abnormalities.

Regarding this matter, authors submitted written plans on the measures and reports of the measures to the proper authorities, and it is believed that the results obtained herein will contribute to future applications of the insolubilizing method on heavy metal contaminated soil.

CONCLUSIONS

Examples of application of the rotary crushing and diffusive mixing method and ion adsorption method in lowlands were presented for ground improvement technology and technology to restore the ground environment, including cases in which tests were performed on similar ground.

Specifically, at first, following outcomes were obtained through applying RCDM to various common problems of soft ground in the lowland.

1) As an application example to levee body material, the gatado fine clay and river gravel were blended at the ratio of 1:2.7. The cone index was more than necessary strength and then it was confirmed the gatado fine clay is good enough as earth fill for embankment.

2) The dredged soil and sediment generated from site excavation which includes a significant amount of rubble (concrete remnants) were applied to embankment material after adding 12% of cement. The uniaxial compression strength reached q_u=300 kN/m^2 and thus these material can be used for the embankment.

3) It was possible to effectively separate underground reed stems that are unsuitable for embankment material. Ability to improve cohesive soil containing underground reed stems was successfully demonstrated.

4) As an application to material deposited by tsunamis, it was confirmed that mixed rubble cam be appropriately processed as embankment material. At present, the rotary crushing and diffusive mixing method

(RCDM) is actually used for improving the tsunami deposits in Tohoku tsunami-stricken areas.

Secondly, as some test applications to restoration of polluted ground by naturally derived hazardous heavy metals, RCDM and/or the ion adsorption technology were examined. These two technologies shown good remediation of the polluted ground and thus they will significantly contribute to the field of geo-environment in the future.

REFERENCES

Kadowaki, M., Ishinohachi, S., Nakajima, N., Oshiki, H. and Yamano, M. (2011). Applicability of rotary crushing and mixing method for the purpose of removing reeds from clumped cohesive soil mixed with underground reed stems. Japan Society of Civil Engineers, 66th Annual Meeting 6-348: 695-696.

Mishima, Y., Araki, H., Ohno, M. and Suhara, H. (2013). Research on phosphate adsorption, desorption and generation characteristics of Nano-size Layered hydroxide (NLDH). Research Meeting of Sewage system, JSWA, 271-273. (In Japanese)

Mishima, Y., Ohno, M., Suhara, H., Araki, H. (2013). Research on phosphorus recovery by using nano-size layered double hydroxide (NLDH). J JSCE, G (Environmental Research), 69(7): III_129-III_135.

Ohno, M., Sugiyama, S., Yokota, S. and Yamazaki, A., (2010). Water purification system by using the nano-crystalline layered double hydroxides (NLDH). J. Clay Science Society of Japan, 49(3):108-112.

Ohno, M., Kajimoto, T., Matsukata, M. and Yamazaki, A. (2007). Development of low- concentration boron/fluorine removal technology by using nano-size layered double hydroxide (NLDH). J. Clay Science Society of Japan, 51: 204-205.

Suhara, H., Arai, Y., Sakurada, H., Nakajima, N., Yokota, S., Akagami, M., Kuroyama, H. and Akiyama, S. (2012). Effective utilization of material deposited by the tsunami from the Tohoku Earthquake through crushing and diffusive mixing technology. Japanese Geotechnical Journal, 7(2): 399-408.

Suhara, H., Arai, Y., Nakakoshi, K.,Akagami, M. and Kuroyama, H. (2011). A case study of a large scale soil/groundwater contamination countermeasure by the volatile organic compound. Japanese Geotechnical Journal, 6(2): 317-329.

Suhara, H. (2009). Countermeasure technology using the soil twister for soil contaminated by VOCs, heavy metals, and dioxins. Kisoko, Feature Issue, Countermeasure Technology for Soil and Groundwater Contamination, 37(11): 65-67.

Suhara, H., Arai, Y., Masuoka, H., Kato, T. (2007). Recycling to construction materials of ceramic by-product fine grain silica sands by crushing and mixing with diffusion. J. JSCE, G (Environmental Research), 63(4):361-365.

The Japanese Geotechnical Society. (2012). Lessons Learned from the 2011 Great East Japan Earthquake and Proposals (secondary): 252-253.