Technical Report

UDC 628 . 49

Development of the Recycling Process for Tsunami Sediment Soil Containing Debris

Yutaka HIRASHIMA* Kohichi HIRAISHI

Abstract

The tsunami of the East Japan earthquake in March 2011 left a great amount of wrecks and soil sediments on the ground. Applying the technology of CaO-improvement of steelmaking slag, Nippon Steel & Sumitomo Metal Corporation, jointly with Nippon Steel & Sumikin Engineering Co., Ltd., has developed a process to recover the usable soil from tsunami sediments mixed with much debris. The developed process was commercially employed for a project of Kamaishi City to treat roughly 200 000 t of tsunami sediments, and it proved effective at reducing sediment treatment costs, supplying useful materials for reconstruction work and thus saving natural resources.

1. Introduction

The tsunami at the East Japan Earthquake in March 2011 left behind approximately 20 million tons of wrecks, or debris, and 10 million tons of soil sediments on the ground. Since the tsunami sediments are composed of mud and sand, with much clay from the sea bottom, and are mixed with debris of wood and metal in order to use them as the material for the foundations of embankments, etc. in the reconstruction work, it is necessary to (i) separate the debris efficiently from earth and sand, and (ii) reform the mud containing fines into highly compactable soil.

On the other hand, steelmaking slag arising from steel refining processes is reformed into CaO-improved soil (lime-based, grain-size-controlled soil). The product soil is in the form of crushed stone, has grain size distribution suitable for compacting, and a high content of calcium oxide (CaO), and thus it readily reacts with water and solidifies. Taking advantage of this characteristic, its use is increasing, wherein it is mixed with slimy sludge dredged from sea bottoms and used for forming mounds, mud flats, etc. or filling up depressions of sea bottoms.

The authors studied the applicability of the technology of producing the CaO-improved soil from steelmaking slag and the rotary crusher/mixer of Nippon Steel & Sumikin Engineering Co., Ltd. to classify and reform tsunami sediments, which has characteristics similar to dredged soil, into material effectively usable for civil engineering work of reconstruction. The present paper reports the results of the study.

2. Body

2.1 High-speed rotary CaO improvement process

2.1.1 Process outlines

Figure 1 schematically illustrates the high-speed rotary CaO improvement process that the authors developed. The process consists of mixing raw tsunami sediments containing debris with the CaO-improved soil (hereinafter referred to simply as “the steelmaking slag”) in a rotary crusher-mixer and classifying the mixture through a vibrating sieve into debris and the soil component (the separated and reformed soil being hereinafter called “the CaO-improved soil”). The rotary crusher-mixer crushes the raw sediment into fine

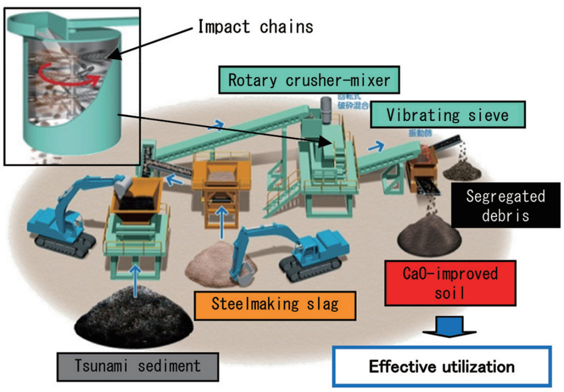


Fig. 1 High-speed rotary CaO-improvement method

* Senior Manager, Slag Marketing Dept., Slag & Cement Div.
2-6-1 Marunouchi, Chiyoda-ku, Tokyo 100-8071

grains by the impact of steel chains rapidly turning in it and mixes the soil component and the steelmaking slag into a homogeneous mixture.

Figure 2 shows an example combination of the feedstock and the products of the developed process. The mud sticking to the debris is detached from it, and only miscellaneous small woodchips of the debris remain in the product soil.

2.1.2 Classification and reforming mechanisms of developed process

By the developed process, the feedstock is adequately and efficiently classified and reformed in the high-speed rotary crusher-mixer using the following mechanisms:

(1) Efficient classification of debris in tsunami sediment

The water-absorbing property and the sand-blasting effect (see **Figs. 3** and **4**) of the steelmaking slag are added to the mixing effect of the rotary crusher-mixer to accelerate the separation of mud from debris and the crushing of mud lumps.

(2) Quick improvement of mud sludge into material good for civil engineering work

As a result of the mixing of mud sludge with the steelmaking slag of low water content, the moisture of the mixture is decreased significantly and the presence of coarse grains of the slag improves the grain size distribution of the product CaO-improved soil. In addition, because the steelmaking slag contains CaO, calcium ions are emitted and adsorbed to the surfaces of mud grains, leading to their agglomeration, and the pozzolanic reaction of soluble calcium helps their solidification (see **Fig. 5**). Owing to these effects, the reformed soil is strengthened and prevented from returning to original mud.

Fig. 2 Example of segregation/improvement

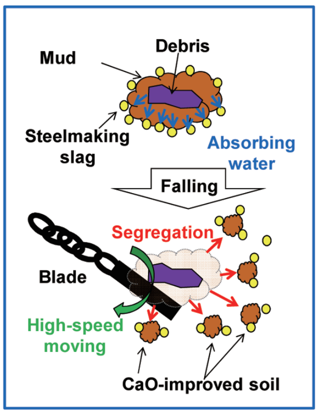


Fig. 3 Image of absorbing water effect

2.2 Verification test of sediment classification and reforming

2.2.1 Tsunami sediments used as specimens

The properties of the tsunami sediments used as the specimens for the test are given in **Table 1**. Original soil A was collected with a plow from a farmland, original soil B was brought from a temporary storage for tsunami sediments, and original soil C was prepared by passing tsunami sediment through a trommel to remove debris. Since original soil A contained field soil, its content of fines was as high as 54%, the water content was 40%, and it was in the form of mud lumps (see Table 4). Original soils B and C contained debris such as wood chips and concrete fragments in considerable amounts (see Table 5). **Figure 6** shows the particle size distributions of the

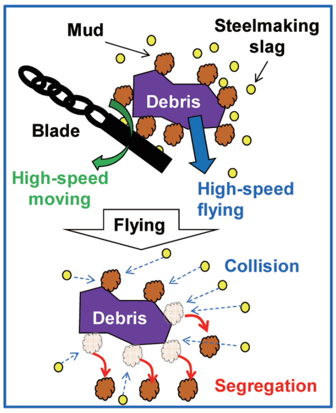


Fig. 4 Image of sandblast effect

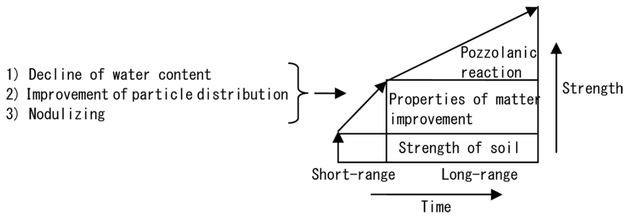


Fig. 5 Schematic illustration of lime strengthening (quoted from a literature of Japan Cement Association)

Table 1 Original sediment soils

Item	Unit	A	B	C
Wet density	g/cm³	1.708	1.817	1.615
Water content	%	40	31	34
Density of soil particles	g/cm³	2.654	2.662	2.701
Fines content (less than 75 μm)	%	54	28	52
Sand content (75 μm–2 mm)	%	46	69	45
Gravel content (more than 2 mm)	%	0	3	3
Liquid limit	%	56.5	45.0	47.3
Plastic limit	%	26.5	25.4	22.8
Originating from		Farmland	Temporary storage	Segregated soil *

* Segregated soil: less than 40 mm in size through trommel (sieving machine)

original soils. None of them conformed to the particle size distribution standard for recycled materials for civil construction use, and their compaction properties were poor because of the low contents of coarse particles.

2.2.2 Steelmaking slag used for test

Table 2 shows the properties of the steelmaking slag used for the test, and **Fig. 7** shows its particle size distribution. It is a granular material equivalent to solidified lime conforming to the environmental safety requirements. CCS-5 was classified to a grain size of roughly 5 mm or less so as to pass through the sieve (standard mesh 20 mm) of the processing plant. The particle size of CCS-20 to -40 is the same as that of iron/steel slag for road construction use, which is CS-20 to -40.

2.2.3 Test procedures and methods

Table 3 shows the test items for process verification. The segregation performance was tested on four cases, i.e., the original soils being charged into the crusher-mixer together with or without the steelmaking slag and screened through a sieve of 10-mm mesh or another of 20-mm. Then, the ease of segregation of the original soils was evaluated by weighing the minus sieve (the CaO-improved soil) and the plus sieve (debris) as well as by visual inspection of their appearances. The workability and stability of the CaO-improved soil was evaluated using a cone test, CBR test, tri-axial compression test, and test banking. Note that the mixing ratio of the steelmaking slag in the tables and graphs is volume ratio (original tsunami sediment: 100%).

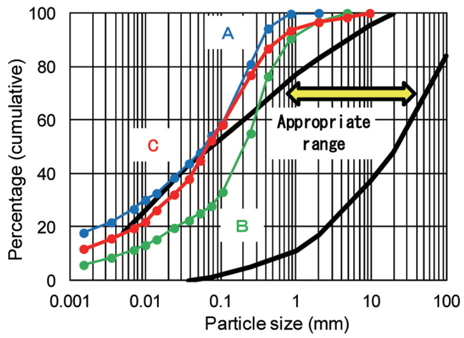


Fig. 6 Particle size distribution of original soil

Table 2 Types and properties of steelmaking slag

Product	Segregation/improvement	CCS-5
	Improvement	CCS-20 CCS-30 CCS-40
Components	CaO content more than 30% (mass%)	CaO/SiO_2 more than 1.5 (mass ratio)
Environmental safety*	8 heavy metal elution/ content	Standard value or less of soil contamination countermeasures act

* According to JIS A 5015 “Steelmaking slag for road” 2013

2.3 Test results

2.3.1 Segregation performance

(1) Original soil A (sediment collected from a farmland)

Table 4 shows the segregation result of original soil A by the present process. When it was mixed with 30% steelmaking slag and treated through the present process, the debris were well separated, the water content of the product soil was lowered, and its particle size distribution improved, which means that the sediment turned into soil good for civil construction use. When original soil A was processed without being mixed with the steelmaking slag, a great amount of mud lumps remained on the sieve and the screened dirt was also in the form of mud lumps. Cement mixing, a common soil improvement method, was conducted for comparison purposes; in this case, although the separation was better than that of the original soil alone, mud lumps remained on the sieve, the cement-reformed soil under the sieve had a high moisture content and when hand squeezed, they easily agglomerated into lumps.

(2) Original soil C (segregated through trommel)

Table 5 shows the processing result of original soil C. Wood pieces in the debris passed through the 20-mm sieve into the segregated soil, but with the 10-mm sieve, there were only small wood fibers in the CaO-improved soil. Actually, with the 20-mm sieve, the debris removed by the screening accounted for 7% of the original

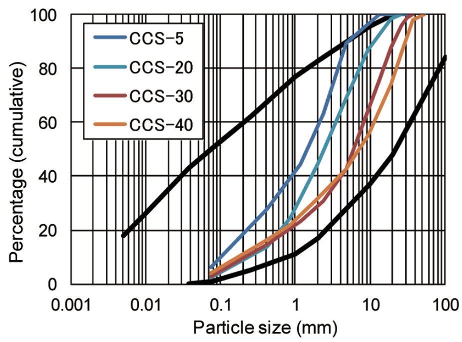


Fig. 7 Particle size distribution of steelmaking slag

Table 3 Items of performance test

Original soil No.		A	B	C
Segregation performance		1) Improved soil 2) Original soil	—	1) Under size 10 mm 2) Under size 20 mm
Strength	Cone (mixing ratio : 0%-30%)	1) CCS-5 mix 2) CCS-30 mix	1) Water content 31% 2) Water content 36% 3) Water content 40%	—
	CBR (mixing ratio : 0%-30%)	1) CCS-5 mix 2) CCS-30 mix	—	—
	Triaxial compression	CCS-30 30% mix	CCS-5 20% mix	—
Test banking		—	1) Improved soil 2) Original soil	

Table 4 Processing result (original soil A)

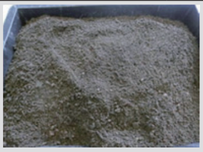
Original soil A (farmland) Water content 40% Fines 54% Sand 46% Gravel 0%		
Case	< 20 mm	20 mm <
Mixed with 30% CCS-5	CaO-improved soil	Debris
		
Sediment only	Mud lumps	Debris and mud lumps
		
(Reference) Mixed with 5% BF slag cement	Cement-improved soil	Debris and mud lumps
		

Table 5 Processing result (original soil C)

Original soil C (segregated through trommel) Water content 34% Fines 52% Sand 45% Gravel 3%		
Mixed with 20% CCS-5 Sieve mesh 20 mm	< 20 mm Improved soil	20 mm < Debris
		
Mass % *	93% + 40% = 133%	7%
Mixed with 20% CCS-5 Sieve mesh 10 mm	< 10 mm Improved soil	10 mm < Debris
		
Mass %	80% + 40% = 120%	20%
	100% original soil + 40% steelmaking slag = 140%	

* Original soil = 100%

soil, but with the 10-mm sieve, the percentage of the debris increased to 20%. In addition, alike the case of original soil A, when the steelmaking slag was mixed at a ratio of 20%, the pieces of debris remaining on the sieve were clean of dirt.

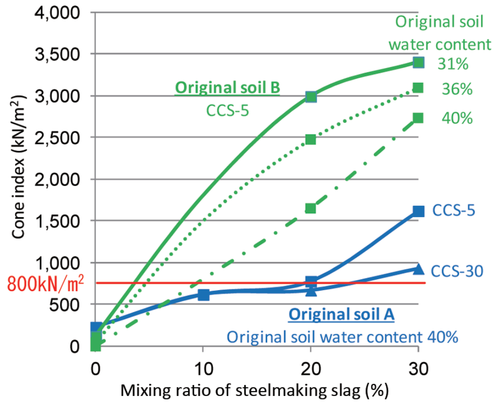


Fig. 8 Relationship between cone index and mixing ratio of steelmaking slag

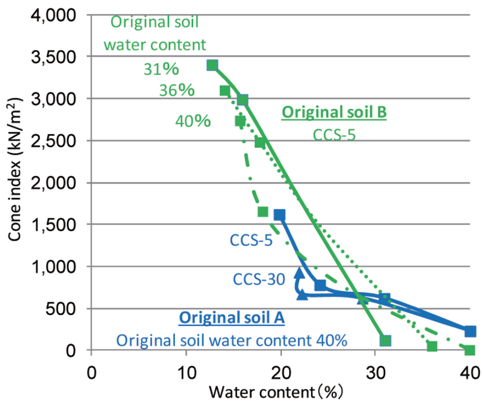


Fig. 9 Relationship between cone index and water content

2.3.2 Tests to confirm performance of CaO-improved soil

(1) Cone test

Figures 8 and **9** show the results of the cone test of the product CaO-improved soils. Figure 8 indicates that even with original soil A of high moister content and high ratio of fines, when the steelmaking slag was mixed to it by 30% (the standard mixing ratio of the present process is 20 to 30%), the cone index was improved to 800 kN/m^2 or higher, clearing the level required in a Ministerial guideline on the reuse of surplus soil. On the other hand, Fig. 9 makes it clear that of the conceivable influencing factors of cone index, water content has a strong influence over it.

(2) CBR test

Figure 10 shows the result of the CBR test under the condition of natural water content. It is clear from the graph that when tsunami deposit is mixed with steelmaking slag by 20% or more, CBR is improved to 3% (the lowest required for roadbeds) or higher.

(3) Tri-axial compression test

The result of the tri-axial compression test is given in **Table 6**. It is clear that with the steelmaking slag mixed by 20 to 30%, the angle of internal friction ϕ is improved to 35°, which is the level of good sand.

2.3.3 Workability and stability at test banking

A bank, 5 m × 5 m in base area and 1 m in height, was made using the CaO-improved soil made by mixing original soil C and the steelmaking slag, and another bank of the same dimensions using the product soil made by processing original soil C without being mixed with the steelmaking slag; **Fig. 11** shows their appearances. With respect to workability, the work was performed in both cases using a common backhoe without requiring any special machines. The cone index at the banking work was around 2 000 kN/m^2, which indicates good compaction.

To test their stability, two depressions, 40 cm in length, 20 cm in width, and 2 cm in depth each, were formed on the flat top of each of the banks, and one of the depressions of each bank was subjected to a cycle of wetting and drying every day. The change in soil strength due to the wetting and drying and natural rainfall was evaluated through cone test; **Fig. 12** shows the result. Where the strength of the bank made of original soil C alone decreased because of the degradation due to the wetting/drying and the erosion due to the rainfall, the bank of the CaO-improved soil derived from original soil C mixed with the steelmaking slag did not show any decrease in strength, demonstrating good stability.

2.4 Actual applications

2.4.1 Commercial application of CaO improvement process

After the demonstrations at two locations given in **Table 7**, the high-speed rotary CaO improvement process was commercially employed for the Disaster Waste Treatment Project of the municipal government of Kamaishi, Iwate Prefecture, from March 2013; **Photo 1** is a panoramic view of the project site. The plant classified and reformed about 200 000 t of tsunami sediment in a period of nine months.

2.4.2 Application of CaO-improved soil

After demonstrations at two locations given in **Table 8**, the improved soil produced through the present process was tentatively used for two real structures, width expansion of a bank and the bed for a quay-front road ("Application tests" in Table 8).

Photo 2 shows some scenes of the quay front level raising work at the Sendai Shiogama Port using the improved soil (the order placed by the regional office of the Ministry of Land, Infrastructure, Transport and Tourism). It became clear through these tests that the reformed soil could be handled with common construction machines, not requiring any special machines.

Further, the tsunami sediment processed into improved soil at the said plant in Kamaishi is scheduled to be used for the land levelling for a sports recreation center and banking for a greenbelt in the city.

3. Closing

The following findings have been obtained through the studies

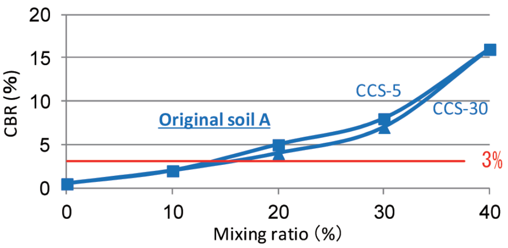


Fig. 10 Relationship between CBR and mixing ratio

Table 6 Result of triaxial compression

	Unit	Original soil A	Original soil B
Angle of internal function ϕ_d	degree	34.8	39.6
Cohesion cd	kN/m^2	25.0	62.2
Mixing ratio	%	30	20
Degree of compaction	%	95	

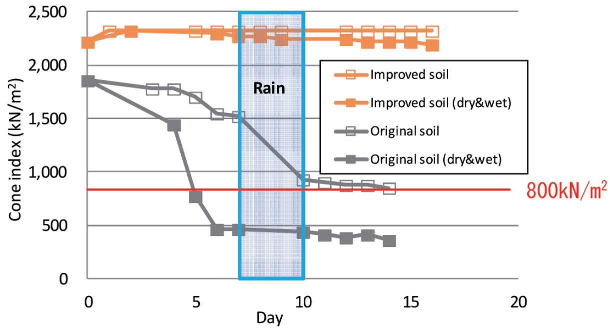


Fig. 12 Changes of cone index under drying and wetting

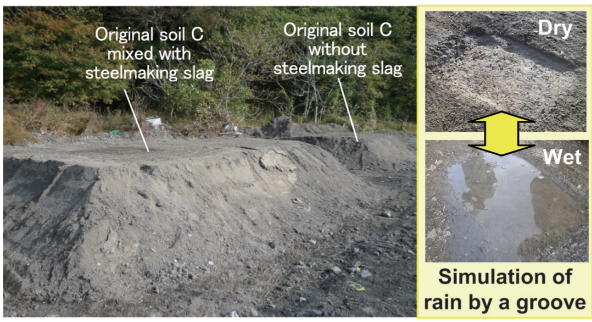


Fig. 11 Result of test banking

Photo 1 High-speed rotary CaO-improvement plant (disaster waste recovery project of Kamaishi City, Iwate)

Table 7 Application examples of high-speed rotary CaO-improvement method

Objective	Client	Place	Quantity	Work period
Demonstration	(at Company's own expense)	Sendai, Miyagi	200 t	Sep. – Nov. 2011
		Kamaishi, Iwate	100 t	Nov. 2011
Commercial use	Kamaishi City	Kamaishi, Iwate	200 000 t	Mar. 2013 – Jan. 2014

Table 8 Applications of CaO-improved soil (including future plan)

Objective	Client	Place	Quantity	Time	Application
Demonstration	(at Company's own expense)	Sendai, Miyagi	2 × 50 m^3	Sep. 2011	Banking
			2 × 3 m^3	Nov. 2011	Road bed
Application tests	Kamaishi City	Kamaishi, Iwate	40 m^3	Nov. 2011	Banking
	Ministry*	Sendai Shiogama Port, Miyagi	80 m^3	Jan. 2012	Road bed
Commercial use	Kamaishi City	Kamaishi, Iwate	200 000 t	(future)	Banking, etc.

* Ministry of Land, Infrastructure, Transport and Tourism

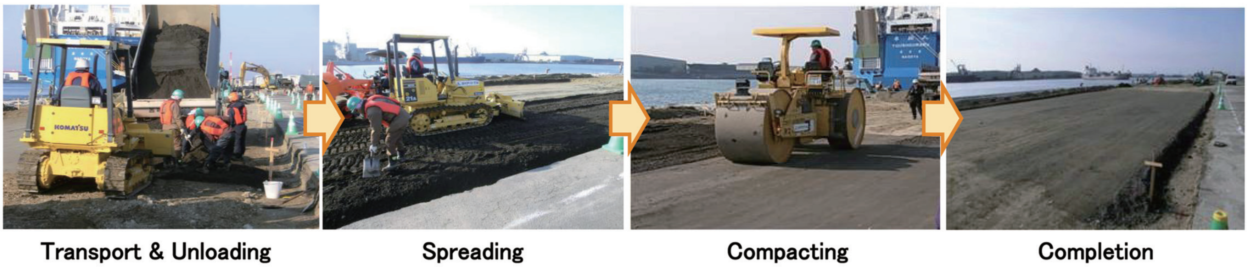


Photo 2 Example of construction (Sendai Shiogama Port)

of segregating and reforming tsunami sediment into soil usable as civil construction material for reconstruction work using a rotary crusher-mixer plant and mixing with steelmaking slag:

(1) The developed process is capable of adequately classifying and reforming tsunami sediment mixed with debris and containing fines and water in high percentages.

(2) As a result of particle size classification and dewatering, the soil reformed through the process exhibits good compacting properties and high strength: its cone index is 800 kN/m^2 or higher (equivalent to the Class 2 Surplus Soil from Construction Work according to a ministerial guideline), the CBR 3% or more, and the angle of internal friction 35° or more.

(3) The improved soil is stable and does not easily turn into mud under rainfall, and thus is effectively usable for various types of reconstruction work such as banking for roads, storm surge barriers, and the like such as for ground raising and levelling.

The developed process was awarded by the Ministry with the Construction Technology Review Certificate in August 2013 and was employed commercially for the Disaster Waste Treatment Project of the municipal government of Kamaishi in order to classify and reform approximately 200 000 t of tsunami sediment. The improved soil of the project is planned to be effectively used for reconstruction work. Steelmaking slag used as the additive in the developed process is useful for reforming other materials such as dredged sludge, construction surplus earth and mud from farmland, and as such, wider applications will be cultivated.

Yutaka HIRASHIMA
Senior Manager
Slag Marketing Dept.
Slag & Cement Div.
2-6-1 Marunouchi, Chiyoda-ku, Tokyo 100-8071

Kohichi HIRAISHI
Senior Manager
Environmental Remediation Dept.
Environmental Solution Div.
Nippon Steel & Sumikin Engineering Co., Ltd.