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Effects of Soil Improvement due to Mixing with Paper Sludge Ash

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Abstract

Paper sludge (PS) ash is cinder that is generated when paper sludge (waste of paper manufacturing) is incinerated. We have previously studied application of PS ash in the construction field (improvement of excavated mud etc.) and found that re-incinerated PS Ash (re-incinerating PS ash at 850～900˚C) had high swelling ability and can be used for environmental clarification of mud. We developed a new soil improvement method and stabilization for withdrawal muck of shield tunnelling work by using re-incinerated PS ash. The main characters of this improvement method are followings.

1. It is possible to improve mud instantly without curing time.
2. It doesn't include harmful components (Chromium (VI) and high alkali like cementious stabilizing materials).
3. It is easy for improved soil to be used again to construction field (banking materials etc.) because it isn't so hard.
4. The quality of waste mud, lacustrine deposit and surrounding water can be enhanced by the improvement using the re-incinerated paper sludge ash.

In this paper, we show the fundamental properties of re-incinerated PS ash and report the results of application to some actual field cases (shield tunnelling etc.). Furthermore we've investigated future application and method to use other PS ashes based on following laboratory tests.

§ 1. Introduction

Waste from construction work such as shield tunneling and excavation has been increasing in recent years. Treatment and disposal of mud, which accounts for more than half the construction waste, is very important in Japan. Such waste should be re-used in construction work as quickly and cost-effectively as possible while paying attention to the surrounding environment. For treating mud or improving soft soils, solidification materials such as cement or lime are generally added to generate or increase strength. Several problems are, however, involved such as the need of temporary storage yards, requirements for curing period, alkali dissolution and difficult construction due to over-solidification of improved soil. For removing mud during earth pressure balance shield tunneling, demand has been arising for low-cost soil improvement material that can improve soils immediately after mixing and is free from chemical

Keywords : cone penetration test, industrial wastes, paper sludge ash, soft soils, soil improvement

problems. Even in the improvement of soft soil where curing is allowable, there have been concerns that cement-type solidification materials may cause dissolution of hexavalent chromium. Thus, environmentally acceptable soil improvement methods are required. The authors have already studied the effective use of ash from paper sludge incineration for construction while the disposal of paper sludge ash was of serious concern (Mochizuki et al. 2002). Our findings showed that paper sludge ash with a high water absorption capacity was effective for improving soft soils or disposing of waste mud. This paper presents the basic soil improvement capabilities, the purifying effect of re-incinerated PS ash that were identified based on laboratory tests, and the results of its application to actual construction cases.

§2. Basic properties of re-incinerated PS ash

2.1 General properties of paper sludge ash

Paper sludge ash is generated by incinerating waste paper sludge from the paper manufacturing process, using fluid bed, stoker or cyclone incinerators, to reduce the weight of the waste paper sludge. Paper sludge ash, a type of plant fiber ash, is mainly composed of silica, alumina and lime because it contains calcium carbonate, kaolin and other materials that are added in the paper manufacturing process. Its pH (hydrogen-ion concentration) ranges widely from a nearly neutral level to around 12 depending on its composition. Paper sludge ash typically has varying physical and chemical properties according to where it is generated. This is attributable to the difference in original material of paper and the type of the incinerator used. The particle density is about 2.2 to 2.9(g/cm^3), the maximum dry density is 0.65 to 0.95(g/cm^3), and the particles have a diameter of 0.005 to 2mm. Silt and fine particles account for more than 50%. Paper sludge ash is self-hardening but even when solidification agents are added, it's strength increases a little. This may be because of the CaO and unincinerated carbon contained in the ash. Paper sludge ash may have varying properties depending on its source. It is a type of waste from a certain industrial product, so it has a relatively stable properties when generated from the same source, a noticeable difference from other types of incinerator ash.

2.2 Re-incineration of paper sludge ash

Re-incinerated PS ash is produced by burning the paper sludge ash obtained from incinerating paper sludge in a cyclone furnace (Fig.1). Approximately three to five percent of unincinerated carbon left in the paper sludge ash is completely removed without using supplementary fuel, by reusing part of the gas emitted from the cyclone furnace to suck it into an incinerator for re-incineration. Minute pores, which are unique to re-incinerated PS ash, are formed as carbon or hydrogen moves out of the paper sludge ash as the ash is re-incinerated.

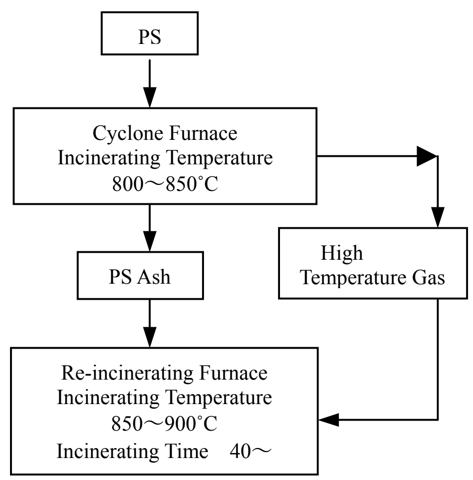

Fig.1 Manufacturing process of re-incinerated PS ash

2.3 Physical properties of re-incinerated PS ash

Table 1 lists the chemical components of re-incinerated PS ash. The material is gray and highly porous. Alumina and silica, the major components, combine and transform into a hard crystal, so the material has high chemical stability. Re-incinerated PS ash has a pH of about eight, so it is nearly free from alkalinity when it mixes with soils. It contains no toxic material and satisfies the environmental quality standards for soil (environmental notification No. 46) in dissolution tests.

Table.1 Chemical Components

Chemical Component	Content (%)
Al_2O_3	22.6
SiO_2	33.8
CaO	18.1
MgO	5.2
Fe_2O_3	1.8
ZnO	0.2
P_2O_5	0.7
TiO_2	2.6
K_2O	0.3

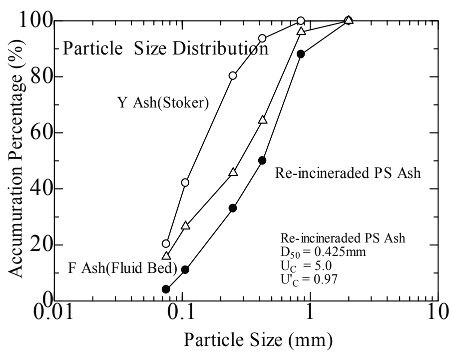

Fig.2 Particle Size Distribution

Photo.1 Re-incinerated PS Ash（×500）

The particle size distribution in re-incinerated PS ash is shown in Fig. 2. The particle size is larger than that in ordinary paper sludge ash (PS ash from stoker and fluid bed furnace etc) and similar to that of sand. Re-incinerated PS ash has numerous minute pores (Photo.1), so it is relatively hydrophilic and has a high water absorption capacity. Water absorption tests for fine aggregate revealed that re-incinerated PS ash has a water absorption rate of about 40%. The critical moisture content in the ash (water absorption capacity) is 115% (Table 2.) The water absorption capacity can be used to treat mud or improve soft soils. Certain levels of compaction are maintained over a wide range of water content (Fig. 3: A ash: re-incinerated PS ash, F ash: fluid bed furnace, Y ash: stoker furnace). The maximum CBR (California bearing ratio), an indicator of load bearing capacity, is lower than the ordinary paper sludge ash because re-incinerated PS ash is not capable of solidifying or consolidating by itself. Certain level of load bearing capacity is secured in a wide range of water content as compaction capacity (Fig. 4).

Table 2 Physical Properties

Physical Property	Value
Particle Density (g/cm^3)	2.376
Bulk Density (g/cm^3)	0.67
Absorption Rate (%)	39.2
Absorption Capacity(%)	115

Note: Absorption Rate：index by JIS A 1109 (Absorption Test), Absorption Capacity：liquid limit of re-incinerated PS ash

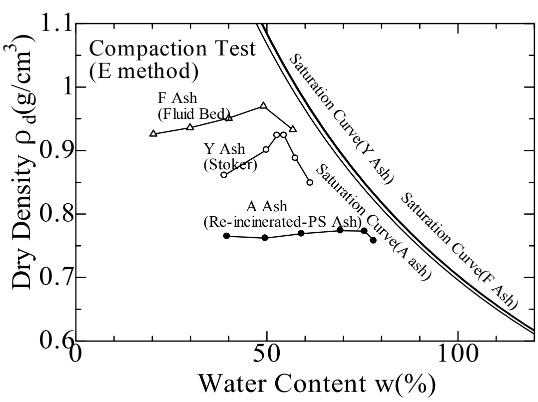

Fig. 3 Characteristics of Compaction Test

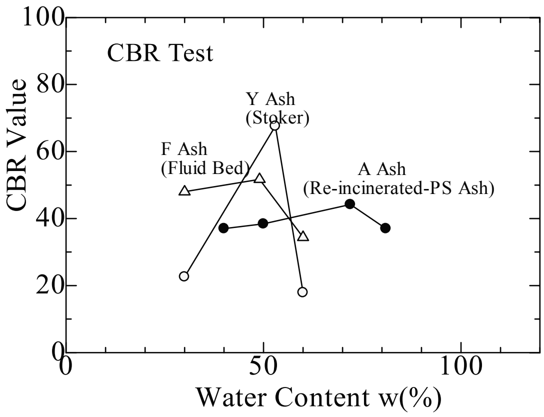

Fig.4 Characteristics of CBR Test

§ 3. Effect of re-incinerated PS ash in soil improvement

3.1 Physical properties of soft soils to be improved

Tests were conducted to verify the effect of re-incinerated PS ash in improving 20 types of soft soil, type a to t (Table 3). The soil types were selected to 1000%. For types a, e, f, h, l, q and t, water content was adjusted during the tests.

Table 3 Physical properties of soft soils

Type of Soil	Particle Density ρ_S (g/cm^3)	Natural Water Content W (%)	Liquid Limit W_L (%)	Plastic Limit W_P (%)	Plasticity Index I_P	Grading Properties: 50% Diameter D_{50} (mm)	Uniformity Coefficient U_C	Coefficient of Curvature U_C	Maximum Particle Size(mm)
a	2.668	40.0	NP	NP	NP	0.377	20.5	0.12	37.5
b	2.625	43.3	51.5	29.8	21.7	0.250	197.2	1.06	26.5
c	2.862	35.3	NP	NP	NP	0.100	26.7	2.96	2.0
d	2.608	110.0	104.7	51.6	53.1	0.013	-	-	2.0
e	2.747	72.0	51.5	43.8	7.7	0.050	-	-	19.0
f	2.885	138.7	163.5	103.9	59.6	0.110	-	-	9.5
g	2.817	56.3	100.3	60.9	39.4	0.090	89.3	3.20	19.0
h	2.698	10.2	274.5	33.8	240.7	-	-	-	0.02
I	2.729	45.8	74.5	41.7	32.8	0.140	-	-	26.5
j	2.565	75.0	96.7	61.6	35.1	0.700	56.0	1.03	37.5
k	2.719	44.7	52.7	27.2	25.5	0.050	-	-	19.0
l	2.624	424.0	195.0	81.0	114.0	0.010	-	-	2.0
m	1.565	956.0	690.0	218.2	471.8	-	-	-	-
n	2.645	42.0	172.0	99.0	73.0	0.2	133.3	5.3	2
o	2.643	49.1	67.3	28.2	39.1	0.003	-	-	0.85
p	2.734	28.6	45.7	26.0	19.7	0.05	100	1	0.85
q	2.700	63.0	41.5	24.7	16.8	0.012	7.78	3.21	0.425
r	2.646	85.0	83.3	41.5	41.8	0.045	-	-	0.25
s	2.721	63.6	33.9	23.9	10.0	0.0082	-	-	2
t	2.651	80.0	74.9	65.3	9.6	0.15	400	0.141	26.5

3.2 Test method

Soil samples were collected for in-situ soil improvement tests. Various strength tests were conducted according to the construction work. This section describes the results of cone penetration tests. The tests were based on the standards for making specimens (Japanese Industrial Standards A 1210) and the method of cone penetration test of compacted soils (JIS A 1228). Re-incinerated PS ash and soft soil are mixed uniformly by soil mixer. Soil improvement generally involves the setting of a curing period while making specimens. Re-incinerated PS ash, however, requires no curing periods, so tests were conducted immediately after improvement.

3.3 Result of test for improvement effects

The test results are listed in Table 4. The relationship between the initial and improvement ratios to secure q_c=200KN/m² is shown in Fig. 5. It is evident that the improvement ratio increased with the initial water content and was smaller for sandy soils

Table 4 Improvement of different soft soils by water content

Type of Soil	Water Content W (%)	Class-4 (q_C=200kN/m^2) Improvement Ratio R(%)	Class-4 Additional Volume (kg/m^3)	Class-3 (q_C=400kN/m^2) Improvement Ratio R(%)	Class-3 Additional Volume (kg/m^3)
a-1	40.0	13	139	15	161
a-2	35.0	8	89	9	100
b	43.3	11	130	12	142
c	35.3	6	85	11	155
d	110.0	59	393	61	407
e-1	72.0	31	276	32	284
e-2	100.0	60	422	61	429
f-1	277.0	100	325	107	345
f-2	183.0	45	200	49	220
g	92.0	21	150	24	175
h-1	300.0	240	669	260	725
h-2	400.0	320	742	335	777
I	-	-	-	-	-
j	75.0	7	62	9	80
k	44.7	10	122	13	158
l-1	424.0	310	663	320	684
l-2	372.3	245	597	250	609
l-3	300.0	200	590	205	605
m	956.0	369	345	394	368
n	42.0	11	135	12	145
o	49.1	15	165	24	266
p	28.6	0	0	2	28
q-1	63.0	38	411	42	453
q-2	52.0	28	323	32	366
q-3	45.0	23	275	27	328
r	85.0	21	172	27	223
s	63.6	26	267	31	317
t-1	80.0	24	213	29	260
t-2	100.0	38	304	44	349

Note: Improvement Ratio R=W/Ws
W: weight of re-incineraed PS ash, Ws: dry weight of soft soil

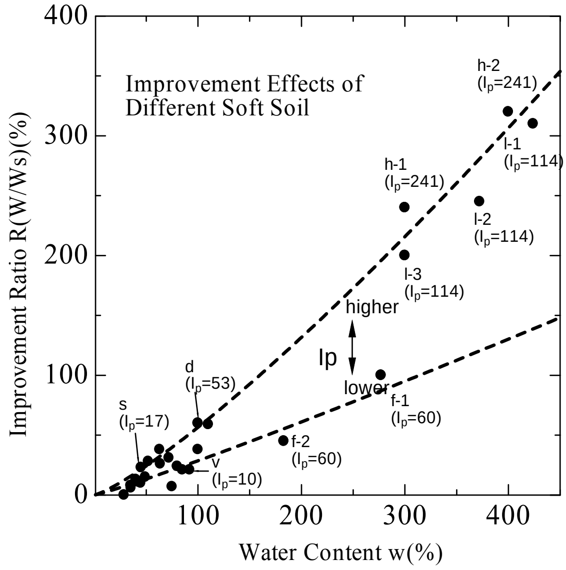

Fig.5 Improvement Effects to sequre q_c=200KN/m²

with a low plasticity index than for cohesive or silty soils with a high plasticity index. A comparison between quicklime in effect of type-b soil improvement is shown in Fig. 6. Comparisons with quicklime and a cement-type solidification agent for type-m soil are shown in Fig. 7. The minimum improvement ratio required to produce the desired strength was higher for re-incinerated PS ash than that for quicklime (required improvement ratio: 11% for re-incinerated PS ash and 6% for quicklime for improving the mud to class-4 surplus mud at construction sites).

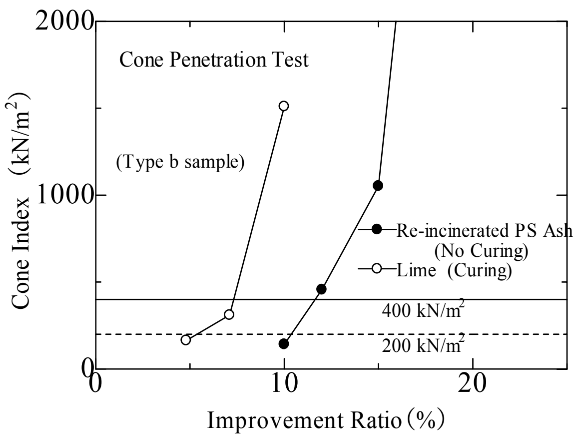

Fig.6 Improvement Effects (Type-b Soil)

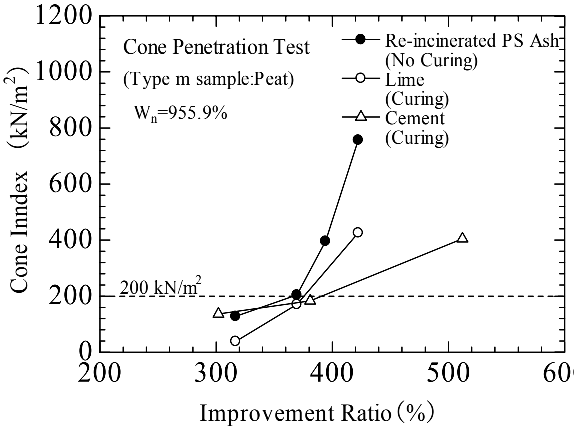

Fig.7 Improvement Effects (Type- m Soil)

The cost was, however, estimated to be less for re-incinerated PS ash than for quicklime. The soil improved with quicklime was cured for one day. It was confirmed that improvement with quicklime without curing provided an improvement ratio equivalent to that by re-incinerated PS ash. In organic soils like the one shown in Fig. 7, re-incinerated PS ash was found to provide the designated strength at a lower improvement ratio than either quicklime or a cement-type solidification agent (even after sufficiently curing of the latter two). Thus, soil improvement with re-incinerated PS ash involves no chemical problems and produces improvement effect immediately. It is also more efficient in soil improvement than existing soil improvement materials. Studies are currently being made to further increase improvement efficiency by combining re-incinerated PS ash with other recycled materials.

§ 4. Purification of mud by using re-incinerated paper sludge ash

4.1 Environmental assessment tests regarding improved soil

To investigate the purification effect of re-incinerated paper sludge ash for lacustrine deposits and waste mud, the environmental assessments shown in Table 5 were carried out. The improvement was applied to pond mud samples A and B collected from different locations. The physical properties of the samples are shown in Table 6, they have very high water content and abundant organic matter. The following tests were performed for a mixed sample of A and B .The results of a physical property improvement test indicate that 400 to 500 kg/m^3 of re-incinerated paper sludge ash is required to improve the cone index (qc) of the pond mud to about 400 kN/m^2.

Table 5 Environmental assessment tests regarding pond mud improvement

Environmental assessment tests	Test method (Tests contents)
･Water flea breeding test	･Acute toxicity, breeding test, Environment Agency's guideline
･Himedaka acute toxicity test	･Acute toxicity (fish), Environment Agency's guideline
･Cultivation of	･Effect on plants, soil culture pot test
･pH test	･pH measurement after improvement
･Chemical analysis	･Chemical analysis of pond water
･Elution test	･Elution test on re-incinerated paper sludge

Table 6 Lacustrine mud properties

Test item		Sample A	Sample B
Particle Density(g/cm^3)		2.554	2.624
Particle size components	Gravel	-	-
	Sand	4	5.9
	Silt	60	67.1
	Clay	36	27
Natural water content w(%)		320	373
Liquid limit WL(%)		100	195
Plastic limit WP(%)		77.1	81
Ignition loss(%)		20.6	-
pH		6.9～7.1	6.9～7.2

The effect of the improvement method was also recognized in the cultivation of komatsuna (Japanese mustard spinach). Greater average stem height and better germination rates were observed in improved mud when compared with unimproved mud. An ecotoxicity test revealed no acute toxicity problems for water flea and himedaka (an orange-red variety of medaka) from either unimproved and improved mud. As shown in Table 7 and Fig. 8, the reproduction inhibition rate in a water flea breeding test exceeded 50% in the unimproved mud, whereas the rate in the improved mud was suppressed to the level comparable to the control case. When only pond water was used, the reproduction inhibition rate was nearly 90% and the death rate of parents was 60%. This indicates that long-term exposure to the pond water affects not only reproduction but also individual survival and the quality of bottom mud and surrounding water can be improved by the bottom mud improvement method using the re-incinerated paper sludge ash.

Table 7 Results of water flea breeding test

Sample item \ Test	Acute toxicity	Average number of offsprings	Standard deviation	Death rate of parents (%)	Reproduction inhibition rate(%)
① Control	None	21.67	1.31	0	------
② Pond water	None	3.00	0.41	60	86.15
③ Mud + pond water	None	9.40	1.64	0	56.62
④ Improved mud + pond water	None	19.80	1.66	0	8.62

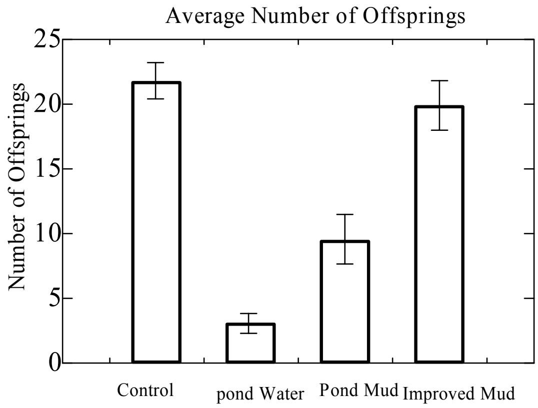

Fig.8 Water flea breeding test

4.2 Test on the adsorption of toxic substances by the re-incinerated paper sludge ash

An investigation was made to determine what substances could be effectively removed by the re-incinerated paper sludge ash. Simulated polluted water was used to test adsorption of a number of toxic substances by the ash.

Lead, cadmium, arsenic, and mercury were selected as common environmental pollutants, and sodium chloride and phosphorus were added to the polluted water to investigate any desalination effect. In the test, 100 g of adsorbent was added to 1 l of simulated polluted water, which was then agitated with a glass rod for 5 min. After agitating the water for 1 h, the supernatant was filtered through a membrane filter having a pore diameter of 0.45 μm to prepare an analytical sample. The concentration of each toxic substance in the sample was measured. To make a comparison with the re-incinerated paper sludge ash, a commercial activated carbon and a natural soil (Kanto Loam) were also used as adsorbents in the test. The specifications of the prepared polluted water and the test items are shown in Table 8. The results of toxic substance removal by adsorption to the re-incinerated paper sludge ash, the activated carbon, and the natural soil in the polluted water are summarized in Table 9. The ability of both the re-incinerated paper sludge ash and the activated carbon to remove lead, cadmium, and mercury by adsorption in the polluted water was confirmed. Arsenic could not be removed by any of the adsorbents. There was little change in the concentrations of chlorine and sodium before and after the treatment indicating no significant desalination by any of the adsorbents. However, the concentration of phosphorus in the polluted water was significantly reduced by adding the re-incinerated paper sludge ash, indicating that phosphoric acid and other nutrient salts can be removed effectively. Because such nutrient salts are the main cause of lacustrine water quality degradation, treatment of lacustrine mud by the ash is considered to be effective not only for the improvement of the physical state of mud but also for water purification by suppressing the elution of nutrient salts.

Table 8 Contaminant concentrations and analytical methods of simulated polluted water

Sample Test Item	Simulated polluted water (before adding) (mg/L)	after adding Re-incinerated PS ash (mg/L)	after adding activated carbon (mg/L)	after adding natural soil (mg/L)	Minimum detection limit (mg/L)
Lead	0.069	<0.001	<0.001	<0.001	0.001
Cadmium	0.071	<0.001	<0.001	0.013	0.001
Arsenic	0.092	0.1	0.13	0.072	0.001
Mercury	0.0047	<0.0005	<0.0005	0.0016	0.0005
Sodium	3900	3700	3800	3800	1
Chlorine	6200	6000	6200	6000	1
Phosphorus	6	1.7	9.4	3.1	0.01

Table 9 Adsorption test results

Contaminant	Contaminant concentration	Analytical method
Lead	0.1mg/L	Acidolysis, ICP emission spectrometry
Cadmium	0.1mg/L	Acidolysis, ICP emission spectrometry
Arsenic	0.1mg/L	Acidolysis, hydride generation atomic absorption spectrometry
Mercury	0.005mg/L	Acidolysis, reduction and evaporation atomic absorption spectrometry
Phosphorus	5～6mg/L	Molybdenum blue absorption spectrometry
Sodium	3,900 to 4,000 mg/l (1% NaCl)	ICP emission spectrometry
Chlorine	6,000 to 6,100 mg/l (1% NaCl)	Ion chromatography

§ 5. Applications to construction field

At present, there are totally more than 30 applications of re-incinerated PS ash in the Japanese construction sector. In this paper, we introduce 4 representative examples (Photo2 ～ 5,Table10). Photo2 shows application of re-incinerated PS ash in the disposal of waste mud during earth pressure balance shield tunnelling.

Photo.2 Application to Shield Tunneling

Photo.3 Application to excavated soil of Open Caisson

Photo.4 Improvement of river bed deposit

In a shield tunneling project where much of the excavation took place in built-up urban areas, the excavated mud was improved continuously without curing period by using puddling mixer due to difficulties in securing the improvement site and the need to improve excavated mud within plant erection.

Photo.5 Improvement system of lacustrine deposit

Photo 3 shows the improvement of soft excavated soil in open caisson and Photo 4 shows improvement of a river bed deposit in dredging. In both of Photos 3 and 4, it was possible to improve the waste material uniformly using only a standard back hoe without a special mixing machine because re-incinerated PS ash could get rid of the most surplus water strongly and momentarily without the partial hardening usually seen for Cement-type material. Photo 5 shows the plant system for improving a large lake deposit after dredging. In this case, the lacustrine sediment had a high clay content and was so cohesive that a pneumatic flow mixing system was used in order to mix and improve uniformly.

Table 10 Records of application

Construction Method	Content of Construction	Improving Volume(m^3)	Classification of Soil	Particle Density ρ_s (g/cm^3)	Cone Index qc (kN/m^2)	Additional Weight W (kg/m^3)	Total Volume (t)
Earth pressure balance shield tunneling	Diameter=1350mm、Length=1621m	5800	Silty Sand with Gravel Silty Sand Cohesive Silt	2.625 2.862 2.858	400	180 140 230	1100
Open Caisson	D_{out}=16m、D_{in}=13.5m、Depth=28.5m	6150	Peat Silt Sand	1.565 2.645 2.795	200 200 200	345 50 130	775
Dredging of River Bed by Vacuum Pump	Dredging area Length=220m	9695	Organic Clay (Dgedged Clay)	2.541 ～ 2.744	400	420	4000
Improvement of Lacustrine Deposit	Pneumatic Flow Mixing System	14000	Organic Clay (Dgedged Clay)	2.901	500	300～400 (Design) Under	5000～6000

Note: Cone Index qc is Improvement Criterion

Additional Weight W is average weight of material per unit volume($1m^3$) of soil

In all applications, the improved soil was used as materials of fill and parking lots etc in the vicinity of the construction field without curing.

§ 6. Comparison with existing soil improvement materials

Re-incinerated PS ash was compared with existing soil improvement materials based on the basic features and construction records. The results are listed in Table 11.

Table 11 shows that re-incinerated PS ash is more environmentally acceptable and produces results more quickly.

§ 7. Effects of other PS ashes in soil improvement

At present, it is necessary to develop not only re-incinerated method but also other means of effectively using PS ash following high demand for this method. We conducted the tests to verify the effects of 25 types of PS ashes from main paper manufacturing factories throughout Japan. These ashes are classified into 4 types by each incinerator.

Table 12 Physical properties and improvement effects of PS ashes

Type of PS Ashes		Particle Density (g/cm^3)	Absorption Ratio (%)	Class-4 SurplusMud q_c=200kN/m2 Improvement Ratio R(%)	Class-3 SurplusMud q_c=400kN/m2 Improvement Ratio R(%)	Curing effect
Re-incineration	A	2.38	39.2	20.2	23.7	No
	B	2.82	27.3	11.9	14.6	No
	C	2.71	43.4	15.1	17.4	No
	D	2.52	41.9	19.5	23.2	No
Cyclone	E	2.45	-	19.0	22.0	Yes
Fluid Bed	F	2.36 ～2.55	(6.3)	13.5	18.0	a little
	G	2.36	-	11.1	15.2	Yes
	H	2.39	-	18.0	24.0	
	I	2.56	-	24.0	29.0	
	J	2.18	-	18.0	22.0	
	K	2.36	-	16.0	20.0	
	L	2.58	-	20.0	24.0	
	M	2.59	-	11.0	15.0	
	N	2.53	-	9.4	11.8	Yes
	O	2.35	-	16.0	20.0	
	P	2.34	-	16.0	20.0	
	Q	2.17	-	15.0	18.0	
	R	2.55	-	21.0	25.0	Yes
	S	2.42	-	21.0	25.0	No
	T	2.58	-	18.7	22.9	
	U	2.52	-	11.0	14.0	No
	V	2.52	-	-	17.0	Yes
	W	2.50	25.7	14.4	17.9	
	X	2.36	-	15.6	21.4	
Stoker	Y	2.29 ～2.36	(11.8)	4.0	8.0	Yes

Physical properties and improvement effects of PS ashes are shown in Table 12 . The tests were based on the method of cone penetration test (JIS A 1228), but the improved specimen was used without curing.

Table 11 Comparison among soil improvement materials

	Re-incinerated PS Ash	Lime-type	Cement-type	High-polymer-type
Toxicity	Neutral and free from toxicity, and can be left unattended for a long time without causing any trouble	Quicklime has been designated as a type-3 hazardous substance by the Fire Service Law. Care should be taken when storing or using the material for construction. pH rises and the material is heated	Not a hazardous substance. Concern exists for the dissolution of hexavalent chromium. pH rises	Neutral and free from toxicity, and can be left unattended for a long time without causing any trouble
Principle of improvement	Physical improvement by reducing the water content of soil using the water absorption capacity of the material	Improvement of physical properties by reducing the water content of soil through water absorption by and heating of the material	Increase of the soil strength through the hydration and solidification of soil by cement	The material acts on the free water in the mud and improves the mud by absorbing the water, solidifying the mud and covering the soil surface. Arching of particles and aggregation of soil
Effects on improvement	Areas out of reach of the material are expected to be improved owing to water absorption. Instantaneous improvement requiring no curing period is possible	Areas where no lime reaches are expected to be improved owing to water absorption	Areas where no cement reaches are not solidified, resulting in irregular improvement	Liquid-type material is used to achieve uniform improvement because only small quantities can be added. No curing is required. Improved soil is not sufficiently solidified
Soil type fit for the material	Cohesive and sandy soils	Cohesive soils	Appropriate for improving sandy soils. Contents of clay and organic substance have impact on the effect of improvement	Appropriate for clay or silt. Care should be taken for soils with high water content
Water content of soil fit for the material	Soils with high water content can be sufficiently improved by selecting an appropriate quantity of the material	Soils that remain muddy after mixing of lime cannot be improved	Soils with high water content harden sufficiently by adding an optimum amount of cement, and thus can be improved	Water content can be reduced only to about 50% for sand, or to 100% for clay。

Soil samples were Fujimori clay as shown in Table 13 and specimens with a water content of 1.1×w_L (liquid limit)were prepared .

Table 13 Physical properties of Soil Sample

Sample Soil	Particle Density ρs(g/cm^3)	Water Content w(%)	I p (%)	Silt (%)	Clay (%)
Fujimori	2.7	45	16.8	54	40

A ash is the material which is applied for construction. Thinking about the characteristics of PS Ashes, it is clear that pH of re-incinerated ashes is nearly neutrality whereas other ashes show alkalinity. Each particle distribution is different according to the type of ash, but it has a tendency that particle sizes of re-incinerated ashes are larger than many other ashes by fluid bed and stoker furnace (Fig.9,10). The results of cone penetration tests show that all PS ashes have an improvement effect. But it is likely that the effect of re-incinerated ash depends on its high water absorption capacity, while other ashes have chemical improvement effects (CaO etc) because some ashes have curing effect and heat during improving. In chemical analysis after cone test, some hydrated compounds (Ca and Al etc) were found. Fig.11 shows curing effect of G and R ashes. This result shows that it is possible to apply other PS ashes to soil improvement and treatment of mud as well as re-incinerated ash.

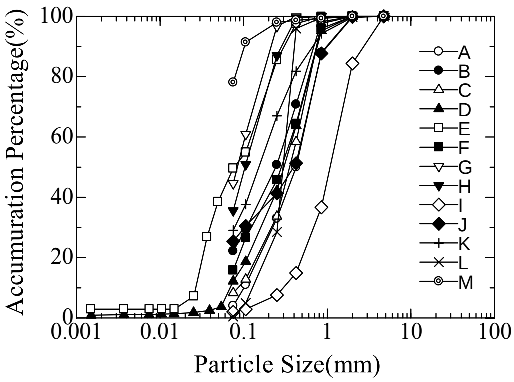

Fig.9 Particle Size Distribution (A～M)

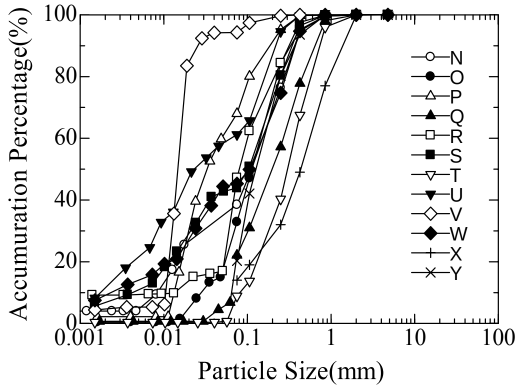

Fig.10 Particle Size Distribution (N～Y)

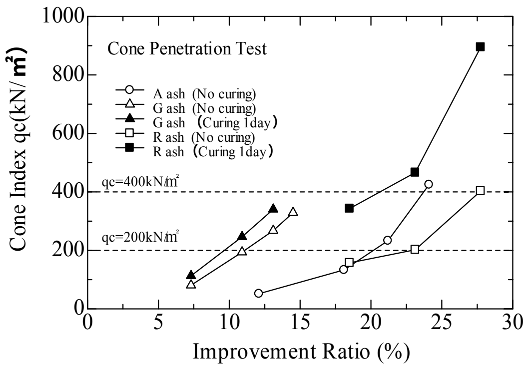

Fig.11 Curing Effect of PS (G,R)

§ 8. Conclusions

This paper described the benefits of re-incinerated PS ash, a soil improvement material made by re-incinerating paper sludge ash, and presented its applications. The material is effective especially for the rapid improvement as required for the waste mud at shield tunneling sites. In order for the method to gain wider acceptance, the following challenges need to be handled.

(i) The water content and the quantity of soil improved by re-incinerated PS ash are slightly higher than those by cement-type solidification materials because re-incinerated PS ash depends on water absorption for mud improvement.

(ii) Systems for transporting re-incinerated PS ash and for using it during construction, and the construction method need to be assessed.
(iii) Storage and supply systems should be established that can respond to changes in demand with time, which are typical of engineering work.
(iv) A quality control system should be established to prevent fluctuation in material composition in different
plants
(v) High cost-performance needs to be ensured (efficiency of transportation should be increased in terms of cost).

In order to make an effective use of re-incinerated PS ash in large quantities in civil engineering work in the future, establishing systems to meet challenges (iii) through (v) are important. Production bases are now being increased and storage facilities such as silos are being enhanced. Studies are also being made to find other means of effectively using paper sludge ash than re-incineration that are suitable to the location and application conditions. Future options include the combination or replacement of re-incinerated PS ash with waste gypsum, coal ash or other recycled material.

References

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Short comment

We developed a new soil improvement method to use paper sludge ash. It is necessary to utilize not only PS ash but also other industrial wastes for construction field in the future to realize zero-emission society.