Research paper

Comparison and analysis of the dust, water, and soil pollution in explosive demolition sites

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Abstract

The objectives of this study were to evaluate effects of a demolition engineering method that fits the environmental standards, and to promote environmental awareness by indicating the characteristics of dust formation as well as the waste water and soil pollution levels in demolition sites, to address the country's pollution problems and the related civil petitions. The dust compound was measured using the light-scattering method, considering the wind direction and speed, and composite soil and wastewater samples were collected from each demolition site and were analyzed using the Korean standard method. The factors that influenced the most the amount of dust that was formed were the surrounding environment of the demolition sites, the applied demolition method, the direction of demolition, and the wind direction at the time of the demolition and of the preparatory steps thereto. The pH range and suspended solid (SS) concentration of the water samples after the explosion were over the limits of the Korean standards of emission and permit because of the lime compound of the rubbles and dust that appeared after the explosive demolition. Moreover, the heavy-material concentrations in the water samples were far below the Korean standards for water preservation, except those of Fe, Mn, Pb, and Hg in the water samples collected from some of the demolition sites, but they did not have harmful effects on the water in the vicinity of the structures that were demolished via explosion. Most of the pollutant compounds that appeared after the demolition did not exceed the limits of the Korean standards for soil preservation, but the concentrations of most of the pollutants in the soil samples increased after the explosive demolition. The analysis list presented herein would be a good reference for finding the status of the environmentally hazardous materials produced in national demolition sites, and it is important to keep monitoring some constituents so that preventive measures against the negative effects of explosive demolition can be established.

Keywords : explosive demolition, fine dust (PM10), water quality, soil pollution, environmentally hazardous materials

1. Introduction

In South Korea, around 2,000 existing low- and middle-rise structures have been replacement with high-rise structures for demolition built in the late 1970 and after[1]. As demolition produces environmental hazards, an environment-friendly demolition method that can help improve the people's living standards must be developed and used, and efforts must be made to increase the people's environmental awareness. Especially, the demolition of skyscrapers being done at high altitudes in downtown demolition sites is a more serious environmental hazard for the vast areas surrounding the sites compared to the demolition of low-rise structures. The downtown demolition occurring mostly in business or residential areas is likely to trigger many civil petitions. In the year 2000 alone in South Korea, the civil petitions with regard to the noise and vibrations caused by downtown demolition numbered 7,480 and increased fivefold in 2007 to 35,568 cases[2)].

Environmentally hazardous factors, such as noise, dust, vibrations, and wastewater, affect the surrounding areas during and after demolition. The past studies focused mainly on the noise and vibrations produced in the process of demolition, but few studies have been conducted on dust formation and water and soil pollution. The construction waste that would be carried away is strewn over the demolition sites, but the fine dust and hyperfine dust produced in demolition sites are also environmental hazards, and the sprinkled water that contains such dust will pollute the water and soil. Moreover, the rainwater that will penetrate the microconstruction remains will cause pollution in the demolition process as well as non−point source pollution in the streams and in the vast extent of stream areas[3)].

Furthermore, the wet construction method, which uses water to cut off the mass, produces wastewater and sludge that will bring the pollutants from the demolition sites to the adjacent areas and streams. According to the database of a past study on the environment evaluation effect in demolition sites, the quality of the water in the surrounding stream areas (the non−point source of rainwater) should be tested, and the dust in the atmosphere should also be evaluated[4)]. No efforts are being made, however, to eliminate the dust therein, even if the outflow of hazardous materials contained by the construction waste coatings and finishing materials produced in the demolition sites can pollute the vast area. In addition, no reference to water and soil pollution in demolition sites has been made.

This study was conducted to evaluate effects of a demolition engineering method that fits the environmental standards, and to promote environmental awareness by indicating the characteristics of dust formation in demolition sites as well as the wastewater and soil pollution levels, to address the country's pollution problems and the related civil petitions.

2. Environmentally hazardous materials in demolition sites

2.1 Dust

There are many factors that affect dust formation : wet concrete, wind speed and direction, precipitation evaporation index, and humidity. The concentration of polluted materials is marked μg m^{-3} as a unit, and fine dust (PM10 : dust below 10 μm in aerodynamic diameter) is the standard for floating dust in most countries. In South Korea, among the environmental−atmosphere standards, the list of total floating dust was deleted and was replaced with the standard of PM10 after 2001. After that, environmental−atmosphere standards were introduced in advanced countries and were upgraded from 150 to 100 μg m^{-3} per day[5)]. Moreover, hyperfine dust, which is below 2.5 μm in diameter and which is known to be the cause of asthma and chronic bronchitis, quickly caught peoples' attention, but there is no regulation with regard to hyperfine dust, only PM10[6)]. The amount of PM10 in South Korea is two to three times higher than that in the advanced countries, and the social−damage cost amounts to 10 trillion Korean won. The administration also needs to come up with a measure to lower the air pollution level in the metropolitan area and in its satellite cities because South Korea has been cited as the worst nation in terms of air pollution among the OECD countries[7)]. A tremendous amount of dust gathers momentarily in demolition sites shortly after explosion, and disappears rapidly afterwards. Among the difficulties in controlling the dust that forms very fast in demolition sites are collecting the dust samples for analysis and preparing the effective measures. The measurement of the dust in demolition sites using the existing mass spectroscopy method is considered ineffective. Among the physical characteristics, mass concentration related to the environment's atmosphere and human health is one of the important variables, and controlling the dust in demolition sites is also very important because the surrounding areas will be directly damaged by the floating dust, and because if the settled dust contains various pollutants, it will also directly damage such areas[8)].

2.2 Water and soil

Water pollution is classified as a non−point source pollution in demolition sites, and determining the extent of the problem using the traditional water pollution standards is unthinkable due to the demolition sites' distinct characteristics, such as the fact that the pollutants in demolition sites are affected by the construction materials of the structures. Lately, concrete is increasingly being used for building structures, as well as light materials that contain much more toxic chemical compounds, such as Cd, Hg, Pb, Cr, Cu, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and oil. These potential toxic materials come from wood, electric materials, plastic, bonds and crack−sealing chemicals, asbestos, fluorescent lamps, tar, and lead compounds in paint, and spill out into the construction sites. These toxic chemicals can be flown directly into the water system by the dispersed dust at the demolition site. Moreover, there is a higher possibility that these toxic chemicals will seep into the soil and water system owing to the water that was scattered to settle the dust, or to the rainwater[9)]. Thus, this study starts with the determination of the toxic chemical types and categories that have a possibility of occurring at demolition sites, and analyzing the characteristics of their occurrence.

3. Results of the measurement and analysis of pollutants

3.1 Outline of a demolition site

This study concentrated on the trends of dust formation and water and soil pollution in every demolition site, and accordingly measured these when many other previous studies handled the noise and vibrations in such sites. Table 1 shows derails of the structure, summary of the demolition method of explosive demolition and weather

Table 1 Characteristics of a demolition site.

	C hotel	H church	W high school	S sports stadium	D sports stadium	G thermal-power plant	Y Thermal-power plant
Structure	Reinforced Rahmen	Shell-reinforced Rahmen	Reinforced Rahmen	Reinforced Rahmen and wall	Wall and part of the stands	Shell-reinforced Rahmen	Shell-reinforced Rahmen
Summary of the demolition sites	Two stories below and ten stories above the ground	Two stories below and nine stories above the ground	Nine stories above the ground	Three-story stand, total floor area 20,000 m^2	Part of the stadium stand	Main structure 45 m, chimney 70 m	Main building 45 m, chimney 59.5 m
Method of explosive demolition	Progressive collapse method	Progressive collapse method	Toppling method	Progressive collapse/ felling method	Progressive collapse method	Progressive collapse method	Felling method
Weather condition	Cloudy, atmospheric humidity 42%	Cloudy, atmospheric humidity 48%	Cloudy, atmospheric humidity 52%	Cloudy, atmospheric humidity 23%	Slightly foggy, atmospheric humidity 88%	Slightly foggy, atmospheric humidity 82%	Cloudy, atmospheric humidity 57%

condition during the explosion in order.

3.2 Materials and method

3.2.1 Dust

According to the standard methods of dust pollution testing, generally, floating particles in the air should be collected with filter paper, and measuring and weighing for the mass concentration of these particles should be done for more than six hours. The light-scattering method was used instead of the mass analysis method because much of the instant dust that is formed from explosive demolition is generated within a few seconds at the time of demolition and settles down within a few minutes. The locations of the measurements that are regarded as representing the pollution level of the region considering the surrounding environment and weather conditions had no obstacles, such as a building or a tree in the surrounding area, and the dust samples were taken at three or four spots with certain distances and directions from the demolition sites. The maximum amount of PM10 was measured using a particulate monitor (Casella CEL Ltd.) at the P1, P2, and P3measurement points of seven demolition sites, and total suspended particulate (TSP), PM 10, PM2.5, and PM1.0 were measured using Dust Mate (Turnkey-Instruments Ltd.) at the P4 measurement point of three demolition sites. They were measured every second before 40–60 minutes and after 30–50 minutes of explosive demolition, and were compared with the differences by elapsed time.

3.2.2 Wastewater

To exclude the exterior influence on the center and the four regional directions of the structure, the water samples were obtained before the sprinkled water reached the surface soil. To determine the suitability of the Korean emission permit standard, the samples were taken from many different places and many times by considering the compound and fluid amounts and the velocity before and after the explosion. The pH and SS were analyzed according to the standard methods[10]. The concentrations of Cu, Fe, Zn, Mn, Cd, Pb, Cr, Cr^{6+}, As, and Hg were measured using an inductively coupled plasma atomic-emission spectrometer (ICP-AES) with Thermo IRIS Interpid II (UK) in wastewater. The standard 3120B digestion method was used for metals analysis. Benzene, toluene, ethylbenzene, xylene (BTEX) were analyzed via GC-MS, using Varian Saturn-III (USA), after the preprocessing of the water samples. The trichloroethylene (TCE) and tetrachloroethylene (TCE) in the aqueous solution were analyzed via GC-ECD using Varian Star 3600cx (USA) after the samples' digestion using the standard 6232B method.

3.2.3 Soil

The soil samples were topsoil (0–15 cm) dried at 25°C temperature and sifted with 10 mesh (<2 mm) after eliminating the organic compounds and weeds from there. The soil samples were taken from different places, were mixed, and were checked to make sure that they weighed 100 g. The heavy-metal samples were kept in a polyethylene vouch, except for Hg, which was kept in a jar with a wide lid. The pH was analyzed according to the standard method for the examination of soil in South Korea[11]. The concentrations of Cd, Cu, Zn, Ni, As, Cr, and Cr^{6+} were determined via flame atomic-absorption spectrometry, with a Shimadzu AA6401F (Japan) atomic-absorption flame emission spectrophotometer, and the presence of Hg in the soil samples was determined via Quick Trace™ Mercury Analyzer M-7500 (USA) Cold Vapor Atomic Absorbance. BTEX was analyzed via GC-MS, using Varian Saturn-III (USA), after the preprocessing of the soil samples.

3.3 Results and discussion

3.3.1 Dust

The PM10 was tested for its basics at the demolition sites that were cited as having the standard environmental atmosphere. The results of the test are as

Table 2 Results of the measurement of PM10 at the individual demolition sites.

Demolition site		C hotel	H church	W high school	S sports stadium	D sports stadium	G thermal−power plant	Y thermal−power plant
Measurement point	P1	Front−left side 57 m	Right−front side 40 m	Right−rear side 50 m	Right−front side 50 m	Front side 30 m	Right side 55 m	Right side 50 m
	P2	Front−right side 45 m	Right−flank side 40 m	Right−flank side 50 m	Left−front side 50 m	Front side 50 m	Right side 63 m	Front side 48 m
	P3	Front−right side 55 m	Right−rear side 40 m	Right−front side 50 m	Front side 50 m	ND*	Right side 90 m	Front side 70 m
	P4	−	−	−	Front side 80 m	Front side 70 m	Right side 120 m	Front side 110m
Average amount of PM10 before the explosion ($\mu g\ m^{-3}$)	P1	366.0	1,536.5	78.0	211.9	358.1	445.0	671.1
	P2	1,621.6	69.9	89.4	75.3	191.2	993.4	860.3
	P3	469.0	4.2	203.0	211.7	ND	487.7	211.8
	P4	−	−	−	59.1	131.3	150.7	−
Average amount of PM10 after the explosion ($\mu g\ m^{-3}$)	P1	8,031.5	4,928.8	87.2	189.5	320.8	5543.0	2,086.1
	P2	10,28.7	121.1	87.6	189.8	173.0	974.5	211.8
	P3	8,053.7	38.2	947.2	189.7	ND	4,474.0	8,438.4
	P4	−	−	−	−	124.3	153.4	ND*
Maximum amount of PM10 by the explosion ($\mu g\ m^{-3}$)	P1	260,469	167,122	347	12,782	1,222	286,708	182,280
	P2	794,836	24,125	156	13,153	1,022	31,749	1,173,400
	P3	529,808	2,158	20,544	7,652	ND	105,442	451,430
	P4	−	−	−	6,528	436.8	1,415	4,384

*ND : Not Detected

follows :

A tremendous amount of fine dust instantly appeared after the explosion and decreased rapidly within minutes. Measuring the dust that instantly appears at the time of the explosion is not an easy task, and collecting test samples and applying the ordinary prevention solution are likewise difficult compared with continually generating dust.

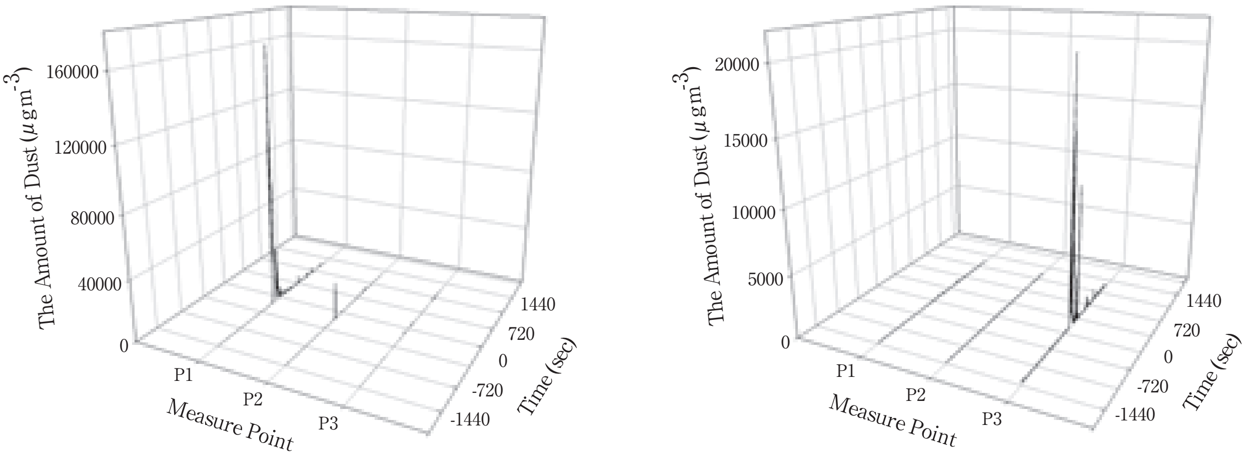
The maximum amounts of PM10 that appeared were 794,836, 167,122, and 20,544 $\mu g\ m^{-3}$, respectively, even though the ten−story buildings (C hotel, H church, and W high school) have similar construction characteristics and sizes. C Hotel was located in a redevelopment area, where construction materials were strewn over, whereas H Church and W High School were surrounded by asphalt and paved roads. As such, the location factor, which causes dust formation, was considered. In addition, prevention solutions such as sprinkling water before the explosion and extending the antidust facilities were established in response to civil petitions as the two sites are located in a large apartment complex. S and D Sports Stadium had an over 10.7−fold difference between them even though they had similar structural characteristics and used the same demolition engineering method. The weather condition was dry, and there was no wind, during the explosion of S Sports Stadium, and the weather was rainy and foggy a day before the explosion of D Sports Stadium, so the dust was not scattered farther. The difference in the amount of fine dust between the thermal power plants of the G and Y sites was about fourfold, and each site consisted of a main building, an annex, and a chimney. Thermal−power plants are usually covered with coal dust, so G Thermal−Power Plant was not only cleaned with water a few days before the explosion ; the coal dust was also washed off by sprinkling water at the site on the day of the explosion. No preparatory steps for dust formation were undertaken, however, because Y Thermal−Power Plant was situated at a distance from the residential areas. Moreover, the direction of the demolition was towards the measurement device, and the wind blowing was also aimed at the measurement device. Thus, the maximum amount of fine dust that was formed was higher. Finally, Y Thermal−Power Plant used the felling method, which falls down towards the front of the demolition structure, instead of the progressive collapse method, which falls down vertically.

Figure 1 shows the maximum amount of fine dust formed, measured at spots with the same distances and different directions between H Church and W High School, and with different distances and the same directions between D Sports Stadium and G Thermal−Power Plant.

After establishing measurement points with direction and distance and measuring the amount of dust, the most influential factors were found to be the surrounding environment of the demolition sites, the applied demolition method, the direction of demolition, and the wind direction at the time of the demolition and of the preparatory steps thereto.

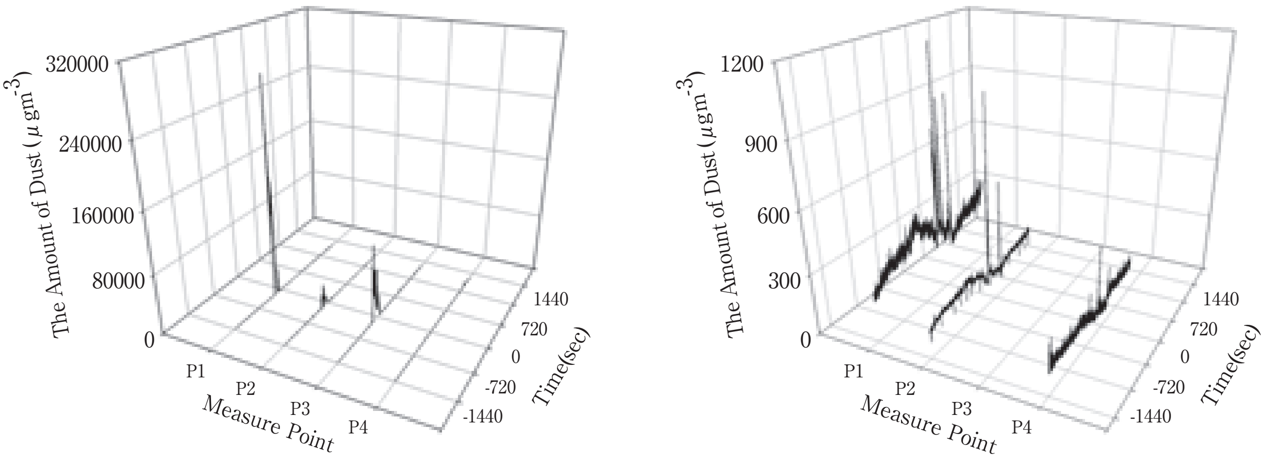
3.3.2 Water quality

The factors that contributed to the pollution of the surrounding water were the construction waste of a



H church W high school

(a) Maximum amount of PM10 measured at spots with the same distances and different directions.



G thermal power plant D sports stadium

(b) Maximum amount of PM10 measured at spots with different distances and the same directions.

Fig. 1 Maximum amount of PM10 measured at spots with the same distances and different directions between H church and W high school (a), and with different distances and the same directions between D sports stadium and G thermal–power plant (b).

Table 3 Water quality concentrations after the demolition.

Compounds	Demolition Sites (mg L^{-1})							Environ. standards
	C hotel	H church	W high school	S sports stadium	D sports stadium	G thermal–power plant	Y thermal–power plant	
pH	10.2	9.02	9.33	13	9.8	10	13.2	5.8~8.6
SS	477	6,310	5,230	18,129	25,044	3,190	26,432	80
Cu	0.036	0.154	0.1	ND	0.812	0.154	ND	3
Fe	6.458	–	10.58	–	197	42.95	48.72	10
Zn	0.224	–	0.22	–	3.492	0.85	2.89	5
Mn	–	–	–	–	14.8	1.794	–	10
Cd	ND	–	ND	ND	0.005	ND	ND	0.1
Pb	0.03	0.079	0.07	0.001	2.76	0.623	ND	0.5
Cr	–	0.307	1.26	0.123	0.802	0.085	0.104	2
Cr^{6+}	0.05	–	ND	–	0.0544	0.06	–	0.5
As	0.008	0.049	ND	0.006	0.119	0.026	ND	0.25
Hg	0.001	0.018	0.024	0.001	0.006	ND	ND	0.005
BTEX	–	–	0.0024	–	–	0.15	0.23	–
TCE	–	–	ND	ND	–	ND	ND	0.3
PCE	–	–	ND	ND	–	ND	ND	0.1

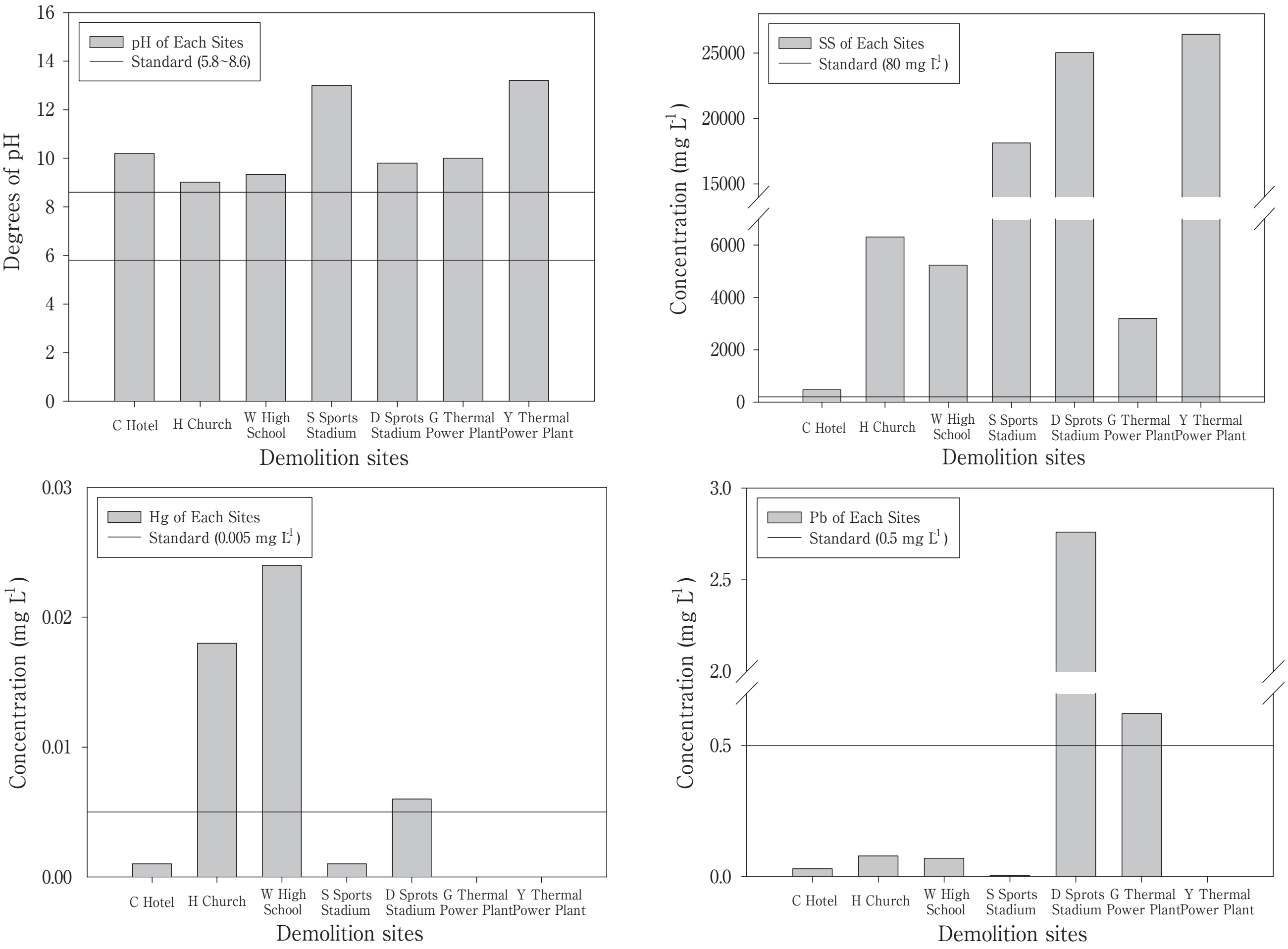


Fig. 2 Concentration of the water samples after the demolition exceeded the limits of the South Korean standards.

concrete slab and wood combined with the water that occurred during plumbing, sprinkled to make the floating dust settle down, and with the rainwater. Especially, the water that was sprinkled to make the floating dust settle down during the destruction period contains harmful materials, such as the dust with pollutants and the industrial waste with the toxic substances in those demolition sites that were considered great factors for endangering the environment. This study referred to the Korean standards of emission and permit, which state the details of the pollutant list by taking the sprinkled water to analyze the harmful materials that were present in the puddles of water at the demolition sites. For the analysis of the result, the South Korean emission and permit standards were applied to the sewage treatment facility. Table 3 shows the concentration of water pollution after the demolition, and the Korean standards of emission and permit.

Both the pH and SS were over the limits of the Korean standards of emission and permit in all the demolition sites, and the results showed that they came from the lime compound of the rubbles and dust. Most of the pollutants were below the standards, but the soluble Fe was 1.1, 19.7, 4.3, and 4.9 times higher than the standards in W high school, D sports stadium, and G and Y thermal–power plant, respectively. In D sports stadium, in addition to soluble Fe, Mn, a heavy metal, was over 1.5 times over the limits, Pb was over 5.5 times over the limits, and Hg (0.006 mg L^{-1}) was slightly over the limits. The concentration of Hg exceeded the limits 3.6 and 4.8 times, respectively, in H church and W high school. Moreover, in W high school, the concentration of BTEX was determined to be 0.0024 mg L^{-1}, showing that the pollution was caused by the gasoline in the oil. Further, BTEX was slightly higher in G and Y thermal–power plant, which was attributed to the toxic materials that came out of the coal dust. Figure 2 was schematized for the pollutants that exceeded the limits of the Korean standards at each demolition site.

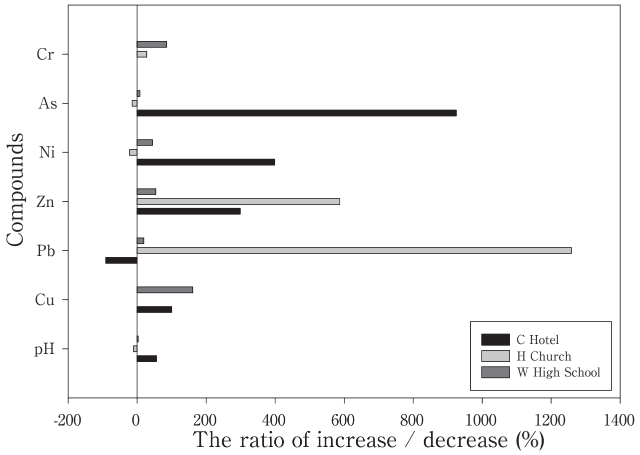
As site G was a thermal–power plant, the pollutants were flown out, unlike in the other structures that were demolished via explosion. As such, when considering the possible pollution conditions for the demolition of special or industrial structures, such as how the structures are used and when they were built, the prevention steps should be carefully planned.

3.3.3 Soil

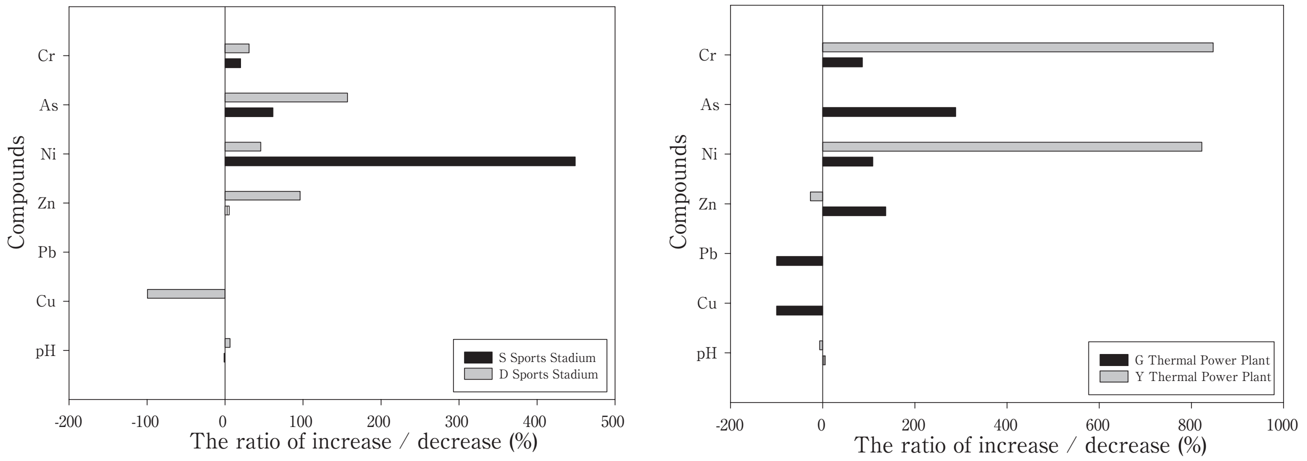
The possible pollutant factors, such as the floating stone grain and the concrete that is wasted in the process of the demolition, affect the surrounding environment. The organics and various micro heavy metals produced by the demolition seep into the surrounding soil and affect it greatly. For quantitative analysis, soil samples were taken before and after the demolition and were compared to determine the differences in their concentrations. Table 4 shows the concentrations of soil pollution before and after

Table 4 Concentrations of soil pollution before and after the explosion at each demolition site.

Compounds	Demolition sites (mg kg^{-1})														Environ. standards
	C hotel		H church		W high school		S sports stadium		D sports stadium		G thermal-power plant		Y thermal-ower plant		
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
pH	7.08	11.04	11.23	10.09	8.75	9.04	11.1	10.98	8.24	8.77	9.88	10.44	12.33	11.54	–
Cd	ND	ND	ND	0.15	0.25	0.29	ND	ND	ND	ND	0.06	0.07	ND	ND	1.5
Cu	0.07	0.14	ND	2.24	29.65	77.37	ND	ND	3.04	0.02	10.18	ND	ND	0.09	50
Pb	1.78	0.16	0.12	1.63	35.4	42.33	ND	ND	ND	ND	9.93	ND	ND	ND	100
Zn	30.63	122.16	99.21	682.29	137.8	212.37	143.55	151.49	73.82	144.91	100.93	239.16	112.63	82.64	300
Ni	2.29	11.43	22.35	17.51	4.84	6.99	0.53	2.91	4.51	6.58	12.48	26.05	69.3	639.37	40
As	0.04	0.41	0.77	0.66	6.29	6.83	1.4	2.26	0.07	0.18	0.99	3.85	ND	3.97	6
Hg	ND	ND	ND	0.01	0.155	0.347	–	–	0.018	0.041	ND	0.08	–	–	4
Cr	–	–	28.43	36.33	13.29	24.62	18.58	22.29	7.84	10.27	19.28	35.95	64.33	609.28	–
Cr^{6+}	0.48	0.06	–	–	ND	ND	–	–	–	–	ND	1.79	–	–	4
BTEX	ND	ND	–	–	ND	ND	–	–	–	–	ND	ND	–	–	–



The ten-story buildings



Sports stadiums

Thermal power plants

Fig. 3 Ratio of increase or decrease of the pollutant concentrations in the soil samples after the explosive demolition.

the explosion at every demolition site, and the limits of the Korean standards for soil preservation.

The soil samples after the explosion in most of the demolition sites showed strong alkalinity (pH 10–13) due to the fact that in general, concrete contains calcium hydroxide, which functions as a steel bar corrosion protector. The floating concrete grain produced after the explosion and settled down by the sprinkled water increased the concentration of pH in the soil samples in the demolition sites. Most of the pollutant compounds that appeared after the demolition did not exceed the limits of the South Korean standards for soil preservation, but

Fig. 3 shows the increase in the concentration of most of the pollutants in the soil samples after the explosive demolition.

Especially, the concentrations of most of the heavy metals increased after the demolition, the concentration of Zn in H church was 2.3 times over the limits, and the concentrations of Cu and As in W high school were 1.5 and 1.1 times over the limits, respectively. The reason for the increased concentration of Zn was that interior and exterior construction materials containing constituents of Zn were used in the construction sites, and 580,000 houses used steel pipe piping water (SPPW) before 1994 in Seoul. The concentrations of Cu, As, and Cr were high in W high school because it used much CCA−treated wood, into which mixture substances of Cr, Cu, and As were artificially inserted to make the wood durable and to extend its life[12]. When demolishing run−down structures, the toxic substances that come from the interior and exterior construction materials and the concrete slabs pollute the soil even if their amounts are below the limits, and they pollute the surrounding areas with heavy metals on a long−term basis. They also cause non−point source pollution with rainwater. As such, when demolishing structures, the possibility of soil pollution should be considered beforehand, and the construction engineering method that will produce the least toxic materials should be chosen.

4. Conclusion

The results that were obtained to respond to the environment acknowledgement and standards by understanding the characteristics of dust formation and the pollution level of the water and soil at demolition sites are as follows :

(1) The factors that influenced the most the amount of dust that was formed were the surrounding environment of the demolition sites, the applied demolition method, the direction of demolition, and the wind direction at the time of the demolition and of the preparatory steps thereto.

(2) As the concentrations of pH, SS, and some heavy metals exceeded the limits, a thorough management system for the construction waste remains is needed. In addition, for the planning that will be done to decrease the dust by sprinkling water, suitable steps are required to prevent indirect pollution from the wastewater that comes from the sprinkled water.

(3) Long−term measures are needed to prevent pollution from the concrete dust grain, which shows strong alkalinity of the pH in the water and soil samples after explosive demolition.

(4) To make the pollution minimal, acceptable measurement is needed by scrutinizing the characteristics and profiles of the structures, as the concentrations of the heavy metals (e.g., Zn, Ni, and Si) were shown to be 10.3 times higher after the demolition of an individual structure, even if the pollution level of the soil in the vicinity is not very high.

(5) Prevention measures are needed, including the selection of harmful materials by analyzing the structures' profiles and purposes when demolishing special or industrial structures.

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