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Original Article

Dust Concentration around the Sites of Demolition Work after the Great Hanshin-Awaji Earthquake

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Abstract

The total dust concentration and the particle size distribution were determined around the sites of demolition associated with the Great Hanshin-Awaji Earthquake, which occurred on January 17, 1995. The total dust concentrations ranged from 0.20 to 0.23 mg/m^3, being about 1.2 to 2.2 times that in the non-demolition area, and intermediate particles (2.1-11.0μm) made up a large proportion of the dust. The dust concentrations were not influenced by the weather on the day preceding measurement around the sites of demolition of concrete buildings, whereas the values decreased to about half around the sites of demolition of wooden buildings, nearly the same concentration in the control areas, when it had rained on the previous day. The dust concentrations increased compared with that in an average year but to the degree of the upper limit of the environmental standard (1 hr-value<0.20 mg/m^3) . The dust due to the smoke of Mt. Sakurajima in the surrounding areas accounted for a higher proportion of large particles (>11.0μm) than in the earthquake-devastated area. The concentration of respirable dust (<7.07μm) in a worker engaged in demolition was 4.0 mg/m^3, being twice the recommended concentration (2 mg/m^3) of the Japan Society for Occupational Health. It was thus considered that workers should use a respiratory protective device.

Key words: airborne particle, Hanshin-Awaji earthquake, demolition, particle size, weather

Introduction

An earthquake directly above the focus, which was located in the northern part of Awaji Island, measuring 7.2 on the Richter scale with an intensity of 7 on the Japanese scale hit Kobe and large cities in the Hanshin district at 5:46 a.m. on January 17, 1995. This great earthquake killed more than 5,000 and destroyed or burned down a number of buildings. In Kobe City and other affected areas in the Hanshin district, destroyed buildings have been demolished at the same period of time since the earthquake. Since the sites of demolition work are concentrated in the shopping quarters and densely populated area in the center of Kobe City, people are apprehensive about the effect of considerable amount of inhaled airborne particles on health. Health injury due to dust depends on its chemical characteristics and physical properties, such as particle size. In particular, fine particulate matter, 10μm or less in diameter, in the air may be deposited onto the lung and trachea and causes respiratory dysfunction. According to the environmental standard, it is classified as suspended particulate matter. The air pollution monitoring station reported that the rate of achieving the environmental quality standard was only 61.8 % in 1994 and had been stabilized for more than 10 years before thean [1].

In addition to the low air quality, the Great Hanshin-Awaji Earthquake occurred and dust resulting from the demolition of buildings may have worsened air pollution in the earthquake-devastated area. Therefore, we investigated the dust concentration around the sites of demolition work after the earthquake and also compared it with the particle size of dust produced by natural activity such as volcanic eruption. From the viewpoint of the environmental quality standard, the effect of dust on the health of the general population was also investigated. In addition, we examined the exposure concentration in a worker engaged in demolishing buildings and discussed the permissible concentration.

Methods

Dust collection

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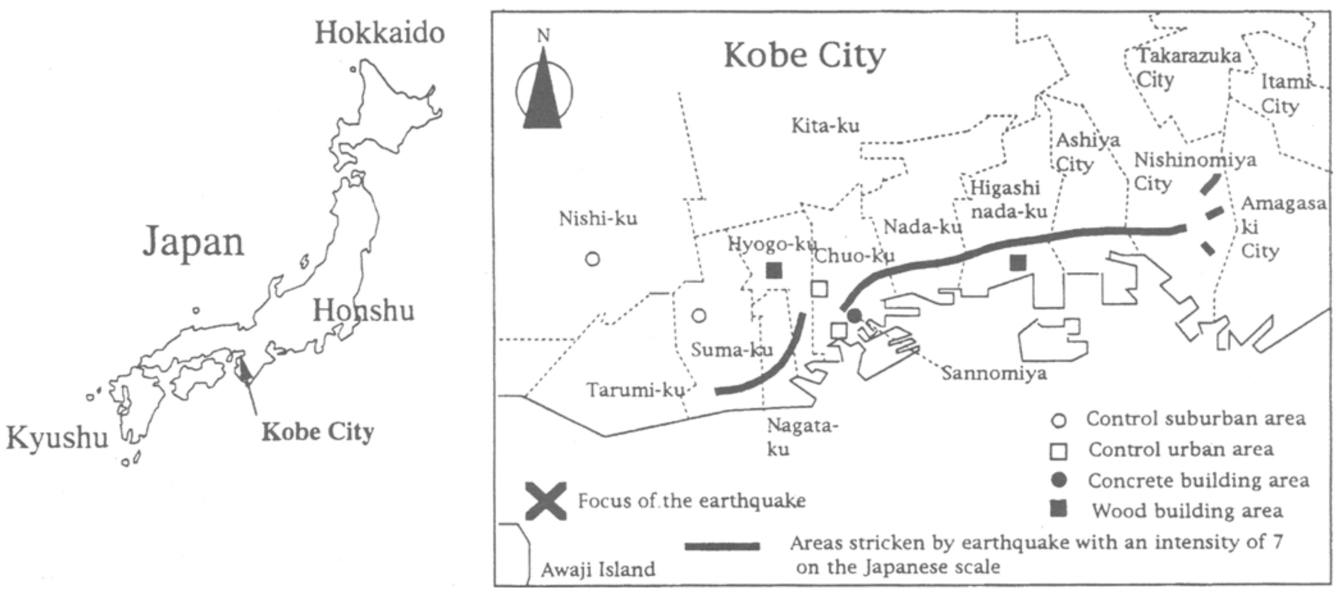

Fig. 1 **Locations of measurement of dust in earthquake-devastated areas and controls.**

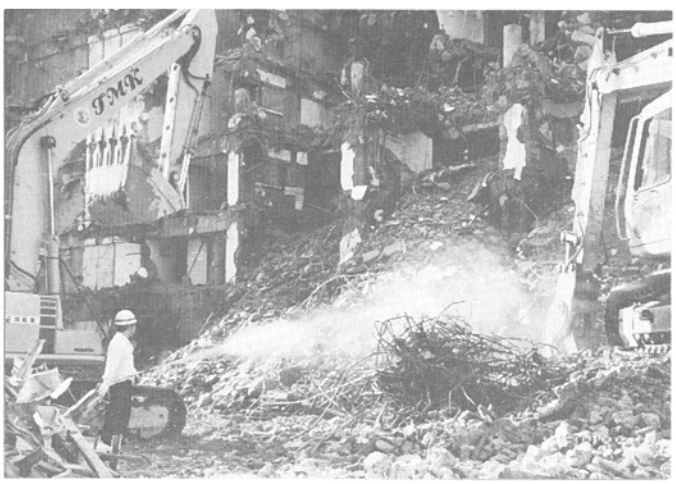

Fig. 2 **Demolition of a concrete building.**

Fig. 3 **Demolition of a wooden building.**

Dust was collected in the earthquake-devastated areas from April to November, 1995. The locations of dust collection in the affected areas are shown in Fig. 1. Two classes of demolition work areas were selected for this study. One was the area where concrete buildings were demolished (hereafter referred to as concrete building area) (Fig. 2) and was the center of Kobe (administrative classification: commercial district) located to the northwest of JR Sannomiya Station and the south of Ikuta Shrine. In this area, almost 100 % of buildings were concrete buildings and the majority of buildings collapsed or were somewhat destroyed. The other one was the area where wooden buildings were demolished (hereafter referred to as wooden building area) (Fig. 3). Four spots in the town area of Kobe where more than half of the buildings were wooden buildings (administrative classification: neighboring commercial district) were selected. Dust collection was performed six times in each area. It was always performed while concrete or wooden buildings were being pulled down.

Two spots in the town area with heavy traffic (administrative classification : neighboring commercial district) and one spot in the residential suburb (administrative classification : first-class low-and high-rise exclusive residential district) with light traffic were selected as the control areas where demolition work was not performed, and dust collection was performed three times and once, respectively.

Water sprinkling for avoiding scattering of dust during demolition work was performed at some sites but not others depending on the restoration of water supply in the concrete building area. In the wooden building area, sprinkling was not performed at all.

Debris after demolition, both concrete buildings and wooden buildings, was loaded into dump trucks successively, while buildings were being pulled down at the same time, and transported to disposal sites.

For the purpose of comparing the composition of dust produced by volcanic activity and after the earthquake, dust collection was performed at locations near Mt. Sakurajima in Kyushu as shown in Fig. 4 in September 1995. There were a total of four collection points: (1) Arimura Lava Observatory, about 4 km distant from the crater; (2) Sakurajima ferry terminal (Kagoshima City) about 9 km distant from the crater; (3) two spots in Kanoya City, about 30 and 40 km distant from the

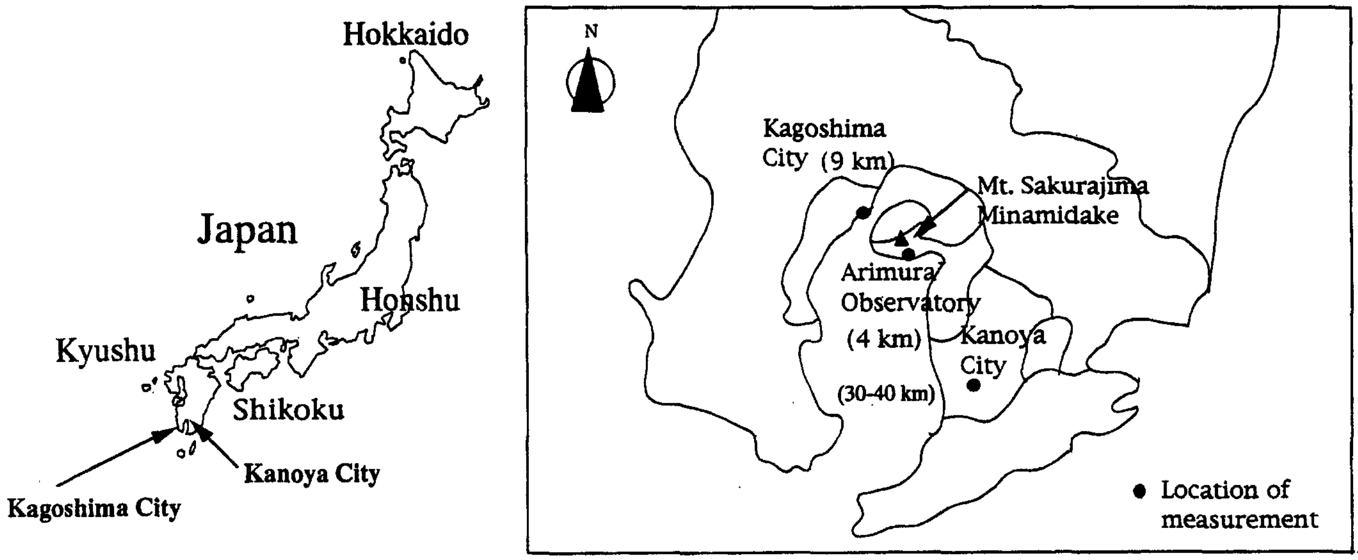

Fig. 4 Locations of measurement of dust in the area around Mt. Sakurajima.

crater.

In order to investigate the state of exposure among workers at the work sites, the atmospheric dust concentration at the site of demolition of a 10-storey apartment building was determined by utilizing three samples. Sampling was performed on two workers by placing personal dust samplers, who sprinkled water onto the debris during the demolition. As a control worker who was unlikely to be exposed to high dust concentration directly, sampling was also performed on a guard who guided dump trucks for carrying debris out at the entrance of the enclosed site of demolition work. Sampling was also performed on a person engaged in reserch activities in a building at a place with heavy traffic, and served as a control of having no connection with demolition work.

Measuring apparatus

Atmospheric dust was collected using an Andersen-type low-volume air sampler (Model AN-200, Shibata Kagakukikai Kogyo Co., Ltd., Tokyo, Japan) . This air sampler can collect dust in the air on filter paper (T60A20, Tokyo Dylec Co., Ltd., Tokyo, Japan) at nine levels according to the particle size of dust [2].

The particle sizes of dust collected aerodynamically (aerodynamic diameters) were over 11.0, 7.0-11.0, 4.7-7.0, 3.3-4.7, 2.1-3.3, 1.1-2.1, 0.65-1.1, 0.43-0.65, and less than 0.43μm. However, only the dust which could be sucked by this sampler was included in the group over 11.0μm. The concentration of respirable dust in the worker was determined by a Roken-type personal dust sampler (Model MP-2N, Shibata Kagakukikai Kogyo) . This sampler can collect respirable dust less than 7.07 μm in diameter, for which is established to meet the work environmental standard, and non-respirable dust which is defined as particles of 7.07μm or greater is size, separately. In this study, the concentration of respirable dust alone was determined.

Procedures

Dust collection was performed on fine or cloudy days near the sites of demolition (on the road about 50-200 m distant from the site of demolition work) or within the demolition site with the air sampler placed at a height of about 1 m above the ground and the air sample was sucked at a flow rate of 28.3 liter/min for 5 working hours. In the areas around Mt. Sakurajima, sampling was performed on the road at each sampling location from 10 a.m. to 3 p.m. on fine or cloudy days.

Personal sampling was performed on the workers for 4 hours and a half during demolition work hours, with the inlet of a personal dust sampler placed on the chest. Dust collection was made in the controls in the same manner.

Filter papers for respective particle sizes were dried in desiccators for 24 hr before and after sampling and weighed using an ultramicrobalance (METTLER TOLEDO, AG245, Mettler Instrument Corp., USA) and the sample weight was calculated from the difference between the weights before and after dust sampling. The total dust concentration was the sum of concentrations of all sizes of dust including particles over 11μm in diameter.

Regarding the weather on the day before dust collection, it was considered "rainy" if rain fell more than half a day, regardless of precipitation. The effect of weather on the concentration and particle size of dust on the day of collection was also investigated.

Results

Total dust concentration

The total dust concentrations determined on days following a fine day at each location of measurement are shown in Figs. 5-A and 5-B. The total dust concentration was 0.165 mg/m^3 in the control urban area with the same traffic volume as the demolition area, being 1.5 times that in the control suburban area with light traffic, 0.113 mg/m^3. The total dust concentrations in the areas where wooden and concrete buildings were demolished were 1.4 and 1.2 times, respectively, the concentration in the control urban area, and 2.0 and 1.8 times, respectively, that in the control suburban area. The total dust concentration within the site of demolition of concrete buildings was 1.9 and 1.3 times that in the control suburban and urban areas, respectively. In the areas around Mt. Sakurajima the total dust concentration was

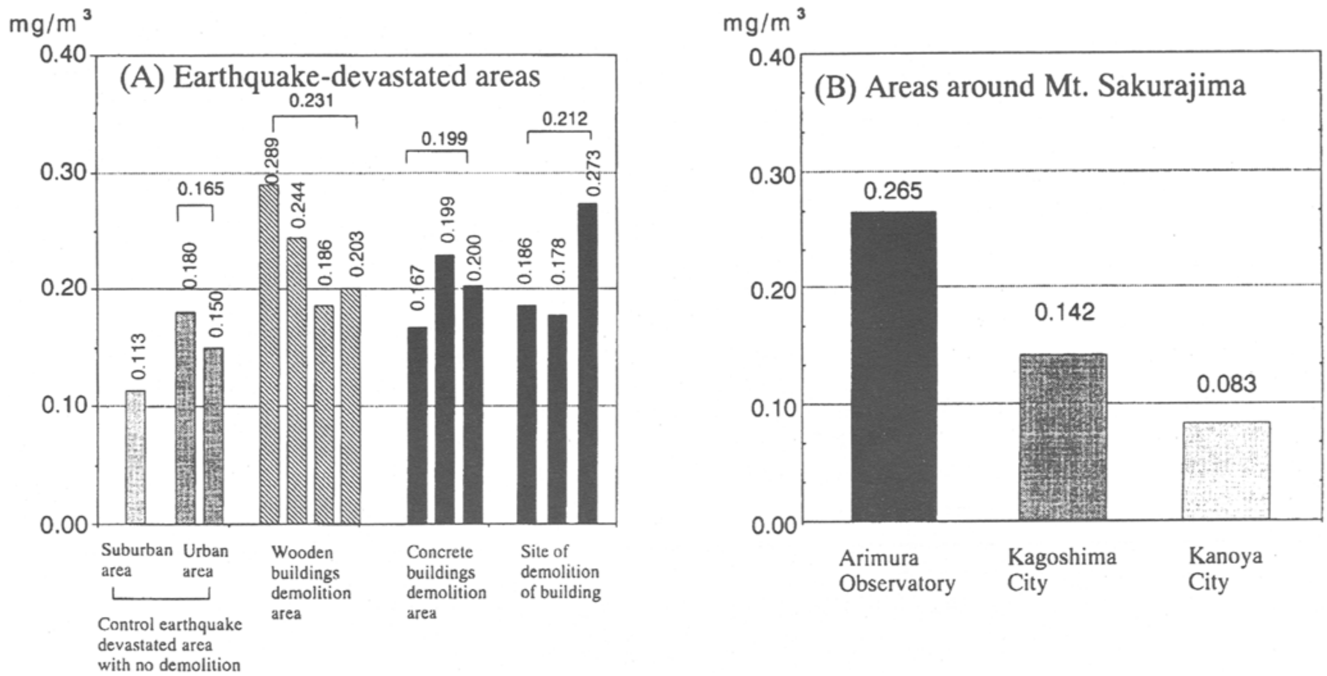

Fig. 5 **Total dust concentrations (measured on days following a fine day). Each column represents a measured value of a site.**

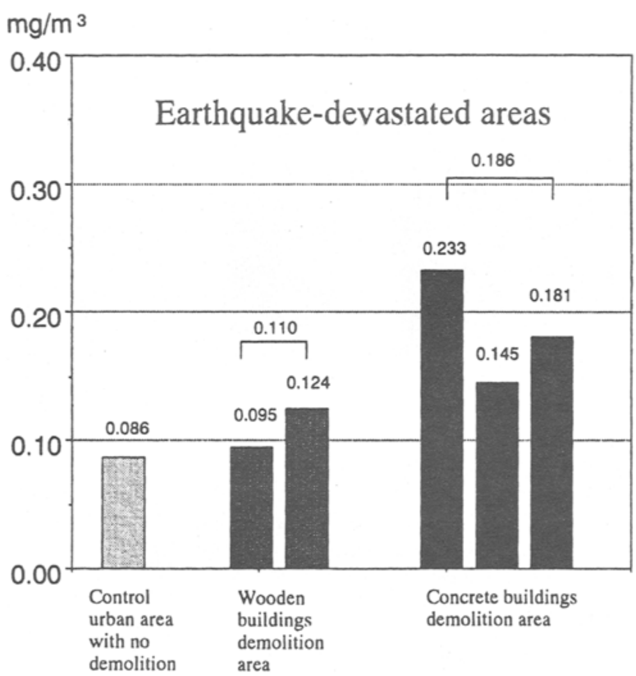

Fig. 6 **Total dust concentrations (measured on days following a rainy day).Each column represents a measured value of a site.**

0.265 mg/m^3 at Arimura Observatory, which is nearest to the crater, being similar to that in the wooden building area in the earthquake-devastated areas. The corresponding figures were 0.142 mg/m^3 in Kagoshima City and 0.083 mg/m^3 in Kanoya City, being very similar to the concentrations in the control urban and suburban areas in the earthquake-devastated areas respectively. The total dust concentrations on the days following a rainy day are shown in Fig. 6. The total dust concentration was 0.086 mg/m^3 in the control urban area, being decreased to about half of that on the days following a fine day. The value was 0.110 mg/m^3 in the wooden building area, being decreased to about half that on days following a fine day. Thus, the total dust concentration depended greatly on the weather on the day before measurement. In concrete building areas, however, the total dust concentration was 0.186 mg/m^3, being not geatly different from that on days following a fine day, and was scarcely influenced by the weather.

Dust concentration by particle size

The concentrations of dust collected classified by particle size on days following a fine day and following a rainy day are shown in Tables I-A and I-B, respectively. The particle size distribution of dust was least in the range of 1.1-2.1μm and showed a bimodal pattern with peaks at less than 1.1μm and over 2.1μm, independent of the weather the day before sampling. In the control suburban and urban areas, dust less than 1.1μm in diameter constituted a greater part, while in concrete and wooden building areas, conversely, dust over 2.1μm constituted a greater part. The particles were then further classified by particle size into three categories according to respiratory function: particles of less than 2.1μm in diameter (small particles) , which can reach alveoli ; those of 2.1-10μm (intermediate particles) , which are deposited onto the pharynx or the bronchi ; and those of over 10 μm (large particles) , which are unlikely to reach beyond the nasal cavity. The concentrations of these thee categories of dust measured at different sites and classified by the weather on the previous day are illustrated in Fig. 7.

In the control urban areas (Fig. 7-A) , concentrations of small particles, intermediate particles and large particles were found to be in decreasing order, while the concentration of each dust particle category tended to decrease half when rain had fallen on the previous day. In the suburban area, intermediate particles showed the highest concentration, and the particle size distribution tended to be the same as that in the demolition areas. In the wooden building area (Fig. 7-B) the concentration of

Table 1 Particle size distribution of dust

(A) Measured on days following a fine day

Particle diameter (μ m)	Earthquake-devastated areas: Control suburban area with no demolition (mg/m³)	Control urban area with no demolition (mg/m³)	Wooden buildings demolition area (mg/m³)	Concrete buildings demolition area (mg/m³)	Site of demolition of building (mg/m³)	Areas around Mt. Sakurajima: Arimura Observatory (mg/m³)	Kagoshima City (mg/m³)	Kanoya City (mg/m³)
0-0.43	0.017	0.027	0.027	0.030	0.035	0.039	0.060	0.020
0.43-0.65	0.016	0.020	0.025	0.015	0.007	0.010	0.014	0.008
0.65-1.1	0.006	0.019	0.020	0.013	0.009	0.007	0.010	0.009
1.1-2.1	0.002	0.013	0.013	0.011	0.014	0.006	0.007	0.007
2.1-3.3	0.006	0.017	0.019	0.017	0.014	0.004	0.007	0.009
3.3-4.7	0.009	0.014	0.033	0.017	0.021	0.008	0.009	0.008
4.7-7.0	0.021	0.016	0.033	0.026	0.029	0.020	0.009	0.008
7.0-11.0	0.017	0.018	0.030	0.032	0.033	0.035	0.009	0.007
>11.0	0.021	0.025	0.032	0.034	0.049	0.138	0.013	0.010
Total dust concentration	0.113	0.165	0.231	0.199	0.212	0.265	0.142	0.083

(B) Measured on days following a rainy day

Particle diameter (μ m)	Earthquake-devastated areas: Control urban area with no demolition (mg/m³)	Wooden buildings demolition area (mg/m³)	Concrete buildings demolition area (mg/m³)
0-0.43	0.014	0.016	0.020
0.43-0.65	0.012	0.010	0.008
0.65-1.1	0.013	0.013	0.009
1.1-2.1	0.007	0.006	0.009
2.1-3.3	0.006	0.009	0.017
3.3-4.7	0.009	0.013	0.028
4.7-7.0	0.006	0.014	0.025
7.0-11.0	0.007	0.016	0.031
>11.0	0.010	0.020	0.039
Total dust concentration	0.086	0.110	0.186

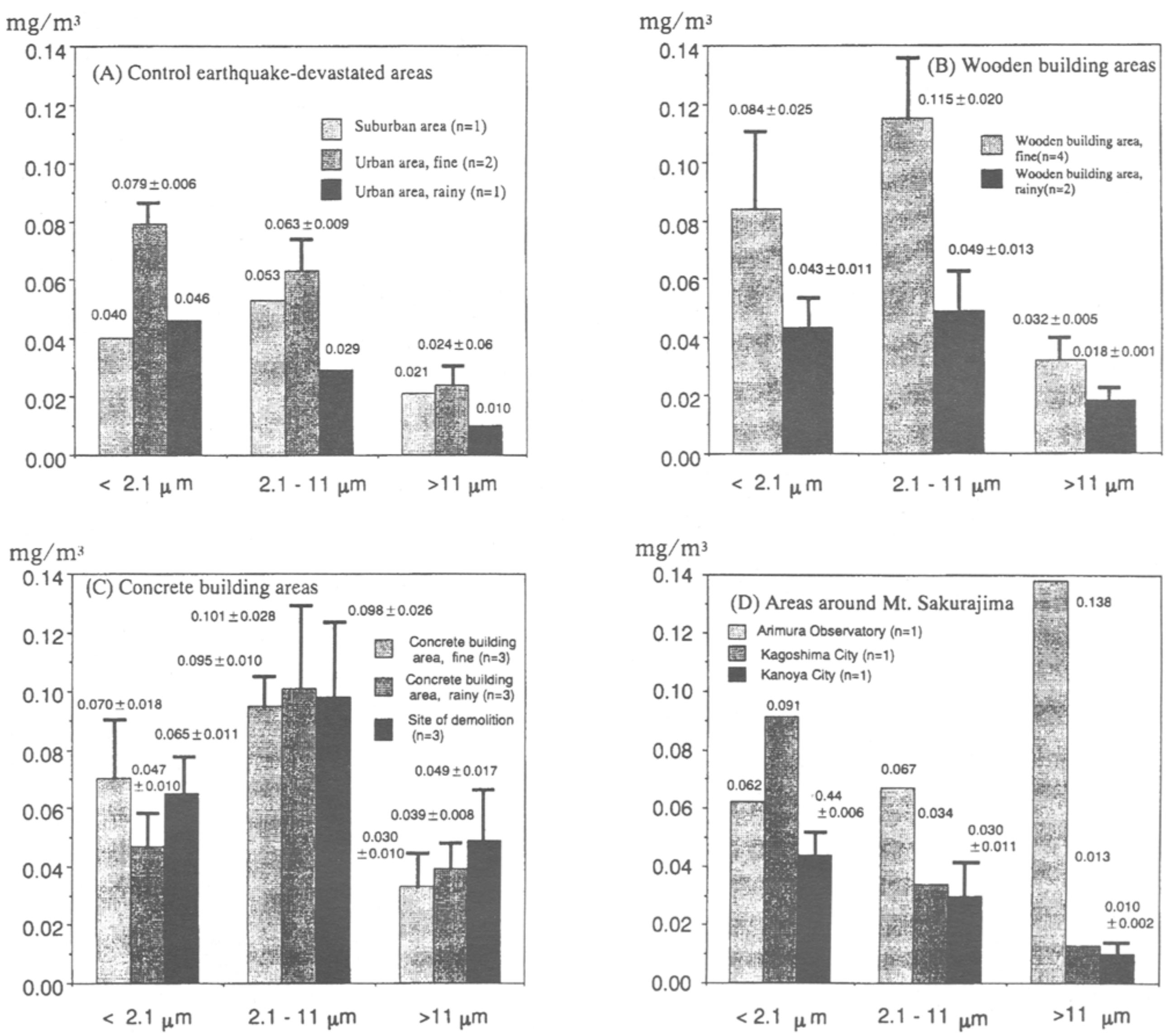

Fig. 7 Dust concentrations classified for particle size.
Values shown are mean ± S.D..
Fine: fine or rain less than half of the time on the day before dust samples were obtained; rainy: rain more than half of the time on the day before dust samples were obtained.

Table 2 Exposure concentrations of dust in workers

Location of measurement		Subject	Weather on the previous day	Concentration (mg/m^3)
Control urban area	Office of Dept. of Public Health, Kobe University School of Medicine	Staff member	Fine	0.22
Workers	Site of demolition of a concrete building	Guard	Fine	0.67
	Site of demolition of a concrete building	Sprinkler	Fine	4.20
	Site of demolition of a concrete building	Sprinkler	Fine	3.80

intermediate particles was the highest, followed by small particles and large particles, regardless of the weather on the previous day. However, it was found that when it rained on the previous day, the concentrations of all particles were low, and the concentrations of small and intermediate particles, in particular, decreased to half of those found on days following a fine day. In the concrete building area (Fig. 7-C) , regardless of the weather on the previous day, the concentration of intermediate particles was the highest as in the wooden building area. When it rained on the previous day, the concentration of small particles slightly decreased but to a less extent when compared with that in the wooden building area.

Within the site of demolition work, the concentrations of small, intermediate and large particles were 0.065, 0.098 and 0.049 mg/m^3, respectively, indicating that the concentrations of intermediate and large particles were higher. The dust concentrations in the areas around Mt. Sakurajima are shown in Fig. 7-D. At Arimura Observatory, which is closest to the crater, large particles accounted for 53 % of all airborne particles. In Kagoshima City, small particles constituted the greatest portion of 66 % of all airborne particles. Intermediate and large particles in excess of 2.1μm were fewer than in the control urban area in the earthquake-devastated areas. In Kanoya City, which is far distant from Mt. Sakurajima, the dust showed the same particle size distribution and concentrations as in the control urban area in the earthquake-devastated areas on days following a rainy day.

Exposure concentrations of dust in workers (Table 2)

The concentration of inhaled dust found in the indoor worker (control) in the urban area where demolition work was not done was 0.22 mg/m^3. Moreover, the corresponding concentration found in the guard (control) who was not directly engaged in demolition work at the site was 0.67 mg/m^3, being about three times the concentration of that found in the indoor worker within the building. The average exposure concentration of dust in the two workers employed in water sprinkling at the site of demolition was 4.00 mg/m^3, being about six times the concentration found in the guard present at the same site and about 18 times that of the indoor worker.

Discussion

The Environmental Basic law establishes the environmental quality standards, which are recommended to be maintained to conserve the living environment and protect human health from the five matters including dust. As regards dust, the standard for suspended particulate matter of 10μm or less in diameter is set as a daily average of 1 hr-value of 0.10 mg/m^3 or less and an 1 hr-value of 0.20 mg/m^3 or less. Since an Andersen air sampler, which the authors used, cannot distinguish between particles of 10μm or less, which is defined as suspended particulate matter, and those greater than 10μm, matters of 11μm or less were regarded as substances for which the environmental standard is set in this study.

We determined the dust concentration for 5 hours during demolition work hours. Therefore, the results we obtained were not comparable with the daily average value set as the environmental quality standard. However, the concentrations of dust of 11μm or less in diameter in earthquake - devastated areas did not exceed the environmental standard : 0.14 mg/m^3 in the urban area, 0.20 mg/m^3 in the wooden building area, 0.16 mg/m^3 in the concrete building area, and 0.16 mg/m^3 within the site of demolition work, on days following a fine day as compared with the maximum allowable 1 hr-concentration of 0.20 mg/m^3.

The 1992 survey by the Kobe Environment Bureau[3)] reported that the proportion of the 1 hr-value exceeding 0.20 mg/m^3 in the year was less than 0.1 %. It is considered that the concentration of suspended particulate matter scarcely exceeds the maximum permissible 1 hr-value throughout the year. However, our survey after the earthquake showed that in the area of demolition of wooden buildings on the day following a fine day, the 1 hr-value was 0.20 mg/m^3, which is within the range of the environmental quality standard but the upper limit. It is estimated that the value may exceed the environmental standard on some days according to weather conditions such as the direction of wind and wind velocity. On the other hand, the value was 0.14 mg/m^3 in the control urban area where demolition work was not done and 0.16 mg/m^3 within the site of demolition work where occupational exposure was anticipated. It is postulated that the markedly elevated concentration of airborne particles for a prolonged time is scarcely brought about by demolition per se.

The dust, which occurs from destroyed buildings, consists mostly of inorganic substances in nature and is less irritating than organic substances. Therefore, it is unlikely that the dust has a serious effect on the health of the general population.

Regarding the distribution of particle size of dust, characteristically, the proportion of small particles was larger in the control urban area than in the demolition area. This is probably because in the control urban area, the traffic volume is heavy with the result that automobile exhaust gas becomes a major factor. In contrast, in the demolition area, whether wooden buildings or concrete buildings were demolished, the proportion of intermediate particles was the greatest. This probably indicates that in the demolition area, the dust produced by demolition work, which contained a larger amount of intermediate particles of 2.1-11μm, had a greater influence than automobile exhaust gas.

As to changes in the amount of dust by the weather conditions on the previous day, the rain on the previous day greatly decreased intermediate particles in concentration in the wooden building area but not in the concrete building area. It is probably due to the reason that in the case of concrete buildings, water does not penetrate well into the inner part of the structure even if rain falls and the dust per se is a matter with low hygroscopicity mainly composed of concrete. On the other hand, case of wooden buildings, many of which were completely destroyed. Water can penetrate into the inner part of the structure and the dust contains a large amount of very hygroscopic matters, consisting mainly of earth.

For the purpose of comparison of the quantity and quality of dust produced in association with demolition work after the earthquake, the concentrations of dust due to the smoke of Mt. Sakurajima were determined in the surrounding areas. The total dust concentration decreased proportionally with the distance from Mt. Sakurajima to the location of measurement. Regarding the particle size distribution, at Arimura Observatory (closest to the crater) the amount of fallen dust became abundant when smoke passed over by the wind. The closer to the crater, the greater the proportion of dust of 11μm or more in diameter. In Kagoshima City, since the direction of wind was reverse on the day of measurement and measurement was made around a trunk road with heavy traffic, the dust concentration might be greatly influenced by automobile exhaust gas in addition to the smoke of the volcano. It appeared, therefore, that the proportion of small particles was large as in the control urban area in the earthquake-devastated areas on the day following a fine day. In Kanoya City, which is about 40 km distant from Mt. Sakurajima, the particle size distribution was the same as in the control urban area on the day following a rainy day and the smoke of the volcano did not appear to play a role. This suggests that dust due to volcanic eruption constitutes a greater proportion of large particles and has less effect on the respiratory system than dust in the earthquake-devastated area.

With regard to the effect of dust on the human body, it is well known that in London in December, 1952, smog caused cardiovascular and/or respiratory disorders, resulting in many hospital admissions and deaths. The chief causative factor[4-6] was considered to be airborne particles in smog. Since then, a great number of papers[7-15] have dealt with the health effect of airborne particles from the epidemiological viewpoint in relation to the mortality rate or medical treatment rate associated with cardiovascular and respiratory diseases. These reports described that floating dust influences the respiratory and cardiovascular systems to the same degree as or to a higher degree than environmental pollutants such as SO_2 and NO_2. There are statistical data that particularly in large cities where geographically atmospheric circulation is poor and in large cities in developing countries where emission controls of floating dust and gas from factories and automobiles are loose, the number of deaths in residents, particularly in patients with respiratory or cardiovascular diseases, increases with increasing atmospheric dust concentration. The dust in the areas stricken by this earthquake abounded in intermediate particles. It is, therefore, considered that bronchial mucosa irritation symptoms such as cough and sputum can develop. However, it is also considered that they can be prevented by wearing a mask in most cases.

As regards the health effect of the smoke of Mt. Sakurajima, the number of patients with respiratory diseases or the number of deaths due to respiratory diseases is not statistically greater even in areas chronically exposed to dust and fallen dust than in other areas [16-18]. In such areas, however, respiratory symptoms caused by gaseous matter instead of dust are problems [19].

At the sites of demolition work, unlike in the ordinary environment, the allowable concentrations of dust by type are established by the Japan Society for Occupational Health[20]. According to such guideline, dust produced by demolition work is considered to correspond to third-class dust consisting mainly of inorganic substances, and the recommended allowable concentrations are 2 mg/m^3 for respirable dust of 7.07μm or less in diameter and 8 mg/m^3 for total dust. In the men employed in sprinkling water, who showed the highest concentration, the concentration of the respirable dust was 4.0 mg/m^3, twice the allowable concentration. Therefore, workers engaged in demolition work should wear a respiratory protective device.

The results of this study show that the atmospheric concentration of dust occurred in association with demolition of destroyed buildings after the Great Hanshin-Awaji Earthquake was higher than usual but below the upper limit of the environmental quality standard. It is unlikely that the dust causes the respiratory function of the general population. However, the dust contained a slightly higher percentage of particles of larger size than usual atmosphere and a number of residents complained of irritation of the mucosa of the respiratory tract, trachea and bronchus. Therefore, protective measures, such as wearing a mask or gurgling, should be considered. In the case of workers at sites of demolition work, working management such as wearing a protective device should be recommended since the environmental concentration may exceed the permissible concentration. Furthermore, it is considered that water sprinkling during demolition work is effective as work environmental management in reducing the concentration of dust produced in association with work on the demolition of buildings, especially wooden buildings.

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