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Construction Dust Emission Features and Management and Control Measures-A Case Study of Zhengzhou City, Henan Province

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ABSTRACT

Industrial development and urbanization progress have been rapidly increasing in China, consequently accelerating infrastructure constructions, such as real estates and public facilities. Building construction dust has become one of the main sources of atmospheric particulate matter (PM) pollution in China. In this study, a typical building in Zhengzhou City was taken as an example, wherein the total suspended particle (TSP) and PM_{10} and $PM_{2.5}$ indicators in the foundation excavation phase of the building construction were comprehensively monitored. The emission levels of both indicators were analyzed, and the periodic change laws of dust concentration and the correlations among TSP, PM_{10}, and $PM_{2.5}$ were quantitatively measured. Results indicate that the PM_{10} and $PM_{2.5}$ concentrations at the monitoring points in the downwind direction of prevailing wind were higher than those in the upwind direction. TSP, PM_{10}, and $PM_{2.5}$ concentrations reached the maximum values at 10:00-12:00 in the morning of most days, and the TSP concentration was maintained at 250-500 $\mu g/m^3$. Moreover, the coefficient of determination between TSP and $PM_{10}/PM_{2.5}$ was 0.8164/0.8376, signifying favorable correlations. The proposed management and control measures include perfecting the construction dust pollution control and management system, establishing the responsibility management mechanism of construction dust, realizing the comprehensive refined control of construction dust, promoting the innovation of building construction dust control technology, and improving the environmental consciousness for building construction dust control. These findings can serve as references for construction dust source pollutant emission control and as scientific decision-making bases for environmental researchers and managers in this field.

INTRODUCTION

Various human activities have been causing increasingly severe impacts on the environment. Resource consumption-type economic construction and extensive-type urbanization have aggravated the environmental pollution in China, and the large emission of particulate matters (PMs) is a major contributor of this phenomenon. To improve the atmospheric particulate pollution status in most cities in China, environmental protection is continuously strengthened in various regions and departments. Emissions from various sources have also been controlled. However, air pollution is not optimistic at all. Building construction dust pollution is caused by dust emissions from potential dust sources, such as construction sites, building materials, or buildings in the surrounding atmospheric environment under manual or natural activities. Building construction dust is mainly derived from the following emission processes: (1) on-site earthwork construction (e.g. earthwork excavation using an excavator), (2) dust due to vehicle running processes, and (3) dust from on-site construction machinery and transport vehicles.

The Henan Province in Central China has a large population and is now in a large-scale construction era. Housing construction areas in the building industry increase every year (Fig. 1), accompanied by the commencement and implementation of large-scale constructions. As a result, the particulate pollution problem is becoming increasingly serious. Over the years, construction activities are continuously conducted in various cities in the province. Most construction operations are implemented in an outdoor environment. The transportation, loading and unloading, stacking, and earthwork construction of engineering materials emit large quantities of PMs during the construction process. With the rapid expansion of the construction regions and areas in the Henan Province, PM emissions also rise. Consequently, air pollution in surrounding regions can become more violent than before, thereby causing a series of adverse effects.

EARLIER STUDIES

Scholars have conducted profound studies and published considerable literature regarding the emission features and

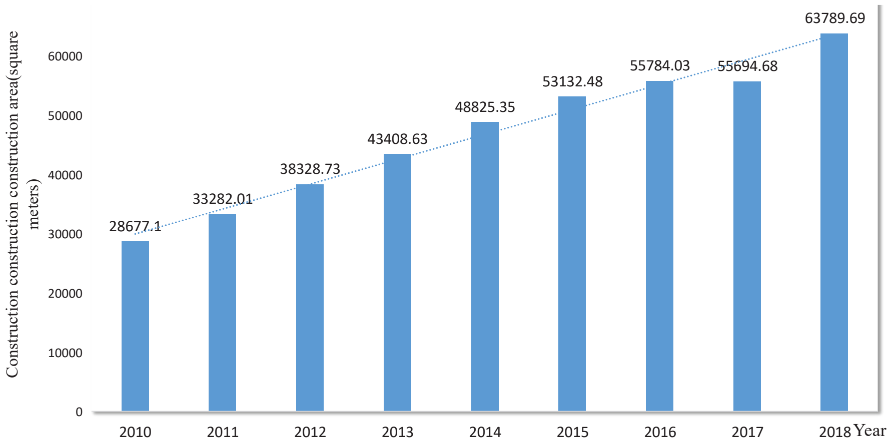

Fig. 1: Housing construction areas in the building industry in Henan Province during 2010-2018.
[Data derived from the database of National Bureau of Statistics of China (http://data.stats.gov.cn/)]

management and control measures of building construction dust. However, no universally applicable quantitative models have been established. The only extensively recognized dust emission estimation method is the Compilation of Air Pollutant Emissions Factors method, which was established by the Environmental Protection Agency of America (EPA). Lee et al. (2001) stated that due to the rapid economic development in Taiwan, large quantities of building sands and gravels are necessary to support the civil constructional engineering development. Their modelling results manifested that the actual dust emission data are associated with wind velocity, soil humidity, soil silt content, and quantity of trucks; this model can serve as a convenient tool in predicting dust emissions from building sand gravel processing plants. Kinsey et al. (2004) reported that when no construction site is available, vehicles carry the dusts and sediments to nearby roads, thereby causing re-entrainment of dusts under the action of external force. In addition, $PM_{2.5}$ is mainly derived from automobile exhausts but is not earth adhered to vehicle wheels. Muleski et al. (2005) conducted an experimental study on the PM_{10} and $PM_{2.5}$ emission factors of building construction-related operations. They discovered that building earth is the most important PM emission contributor, and that truck loading, rubble dumping, slurry, and dirt are the main sources of building dust. Zhao et al. (2006) hypothesized that PMs are the main pollutants in the urban ambient air in North China and performed a dust resuspension experiment in six northern cities in China. Their results indicated that the PM_{10}, construction waste, soil, cement, and coal combustion in the six cities are the primary causes for the increase in resuspended dusts. The rubble industry is a small-scale industry in India where most operations are manually performed. Sivacoumar et al. (2009) investigated the high-dust generation sources of 72 crushing machines and monitored the surrounding communities. Their findings revealed that the environmental dust concentration and occupational exposure level greatly exceed the standard values. Tian et al. (2009) built a mathematical model similar to the exposure profiling method recommended by the EPA to analyse the data of over 40 construction sites in the suburbs of Beijing. This model outputted a favourable scientific basis and use value. Kassomenos et al. (2010) conducted a correlation analysis of the influence factors of PM_{10} concentration and discovered that the PM_{10} in Birmingham is mainly influenced by building dust. They also reported that climatic factors can greatly affect the PM_{10} concentration. According to Guttikunda et al. (2013) PM_{10} pollution is mainly caused by the dusts induced by automobile exhaust gases and building construction, whereas $PM_{2.5}$ is the mixture of automobile exhaust gas, industrial coal combustion, and waste incineration. Peng et al. (2013) introduced a vertical scanning micro pulse laser radar system to determine the PM_{10} and $PM_{2.5}$ emission factors of heavy and light vehicles on a construction site. They also developed a new method to realize the rapid field measurement of PM emissions from urban dust sources. Pianalto et al. (2013) utilized the remote sensing data collected by special land satellite mapping units in the south of Arizona from 1994 to 2009. They found that the dust sources generated by local building construction exert a remarkable effect on air pollution. Li et al. (2014) measured the dust pollution caused by different types of construction activities during the major structural construction phase in two residential areas in Beijing. The total suspended particulate (TSP) concentration and a dust sampling instrument were set as the monitoring index and monitoring equipment, respectively. Their comparative analysis indicated that variations are evident in the dust pollutions induced by different construction activities. Wu et al. (2005) surveyed the building dust prevention and control status in China. They also determined the main sources of construction dusts through content analysis, field investigation, questionnaire survey, and experienced professionals. They further proposed several countermeasures, including formulating pertinent laws and regulations, enacting proper charging schemes, developing feasible monitoring systems, and reinforcing trainings and propagandas on the basis of the survey results. Faber et al. (2015) reported that the emission from construction sites accounted for 17% of the total PM_{10} emission in Germany. By investigating three typical construction sites in the main city areas in Chongqing and collecting data through field investigation, Yongjie et al. determined the PM emission intensity of construction dust and annual average PM emission. They also proposed suggestions for building dust management to serve as decision-making references (Yongjie et al. 2016). Domestic and foreign studies on building construction dust are mainly concentrated on TSP and PM_{10} emission features. Only few researches involve $PM_{2.5}$ emission features. Most studies directly use emission factors but ignore the building emission factors suitable for local conditions. In addition, these studies calculate the quantity of building construction dusts according to the overall unified emission level. Few researches have conducted the analysis on different construction phases. Many studies related to construction dust focus on the estimation of overall dust emission without considering the quantitative dust analysis of internal construction activities of different projects. Thus, determining the construction activities that cause severe dust pollution is difficult. To provide a reference for environmental air quality management, the present study focuses on the analytical study of PM_{10} and $PM_{2.5}$ emission features during the concrete process-foundation excavation-in a typical construction site in Zhengzhou City, Henan Province.

SURVEY AND EXPERIMENTAL METHODS

Respondents

In recent years, large-scale construction works (e.g. buildings, roads, and bridges) are present in Zhengzhou, causing environmental particulate pollution. To objectively reflect the particulate emission levels during foundation excavation processes, a large-scale construction site in the main city area of Zhengzhou was selected as an example of a PM monitoring site. The construction site is a quasi-rectangular foundation pit with a length of 230 m, width of 160 m, and cumulative earth volume of 368,000 m^3. The carrier vehicles were operated in the evening during the construction period, and no carrier vehicle was operated during daytime when the sampling was conducted. Four monitoring points (A, B, C, and D) were set at the four corners of the monitoring site.

EXPERIMENTAL PROCESS

The foundation excavation at the monitoring site lasted for 47 days in 2018. However, the actual sampling time was only 12 days because 17 days were rainy days, and normal construction was not executed for 18 days due to road problems. The TSP and the inhalable PMs (i.e., PM_{10} and $PM_{2.5}$) were selected as dust monitoring indicators during the deep foundation excavation phase. The measuring meteorological parameters include temperature, humidity, wind direction, and wind velocity.

***Preparation of filter membrane samples*:** Quartz filter membrane was used to collect PM_{10} and $PM_{2.5}$. The membrane was preprocessed before sampling and placed in a muffle furnace for 8 h at 500°C for calcination. The membranes were allowed to cool and then dried for 24 h in a dryer. An electronic balance with a precision of ± 0.01 mg was used to weigh the membranes until a constant weight was reached. The mean value of three measured weights was taken as the mass.

***Preparation of sampling instrument*:** A flow meter was used to calibrate the flow quantity of the atmospheric particulate sampler one day before sampling. The cutter head, filter membrane groove, and other parts of the sampler were scrubbed using dust-free paper and absolute alcohol to avoid polluting the filter membrane.

***Collection of PM samples*:** The four monitoring points A, B, C, and D were respectively set at the east, south, west, and north corners of the monitoring site. The TH-150AII intelligent medium-flow sampler (Wuhan Tianhong Environmental Protection Industry Co. Ltd) was used, and the PM_{10} and $PM_{2.5}$ cutter heads were respectively utilized to obtain the PM_{10} and $PM_{2.5}$ samples at the height of 2.5 m above the ground (air flow quantity = 100 L/min). The construction peak was from 10:00 to 15:00, during which sampling was performed for 5 h. After completing the sampling, related parameters were recorded, and the filter membrane was sealed in the dryer for the follow-up analysis.

Processing of PM filter membrane samples: The mass of the filter was obtained using the method described later. The mass difference of the filter membrane before and after sampling was divided by the acquired standard volume in the current sampling process to calculate the corresponding PM_{10} and $PM_{2.5}$ concentrations by using the formula below.

$$c_{pm} = \frac{c_1 - c_2}{v}, \qquad \ldots(1)$$

Where, c_{pm} is the mean concentration of atmospheric PMs, μg/m^3; c_1 and c_2 are respectively the masses of the filter membrane before and after sampling, *mg*; *v* is the sampling volume, m^3.

Acquisition of related data: An anemorumbometer was used to conduct the simultaneous monitoring of the instantaneous and average wind speeds and directions in the construction site. The recorded PM data from the monitoring station beside the construction site served as the background values of the PM emissions. Other data, including barometric pressure, temperature, and relative humidity in this region in Zhengzhou were collected from the Henan meteorological website.

RESULT ANALYSIS

Analysis of PM$_{10}$ and PM$_{2.5}$ Emissions

The overall PM$_{10}$ and PM$_{2.5}$ concentrations at points B and D were relatively large, whereas those at points A and C were relatively small (Figs. 2 and 3). According to the data collected by the on-site anemorumbometer, the prevailing wind on the monitoring site during the sampling period was the northeast wind, in which points A and C were located in the upwind direction, whereas points B and D were in the downwind direction. The PM$_{10}$ and PM$_{2.5}$ concentrations at point B (489 μg/m^3) on June 6 were higher than those in other sampling days (245 μg/m^3) because the work intensity at the construction site that day was large. The wind speed also reached the maximum value of 2.17 m/s during the sampling period, and both PM concentrations were partially high.

Periodic Change Laws of Dust Concentration

The per hour mean concentrations of TSP, PM$_{10}$, and PM2.5 were used to draw the time-dependent graph to observe the change laws of the three concentrations in one day. Twelve data were compared, all of which demonstrated strong similarities. The data from May 18 were selected as the representative for the detailed analysis. The wind speed and direction on this day were relatively stable, and the difference between points B and D was minor. The data of the former are displayed in Fig. 4.

The TPS, PM$_{10}$, and PM$_{2.5}$ concentrations reached the maximum values at 10:00-12:00 before gradually declining. During lunch break (12:00-13:00), the concentrations dropped and then increased. The TSP concentration was constant at 250-500 μg/m^3.

Correlation Analysis of TSP, PM$_{10}$ and PM$_{2.5}$

The obtained TSP concentration was used to perform a correlation analysis of the monitored PM$_{10}$ and PM$_{2.5}$ concentrations (Fig. 5). The variations in the TSP, PM$_{10}$, and PM$_{2.5}$ concentrations were kept identical, which implies that the three might have exhibited favourable correlations among each other. This inference was presented in Fig. 5. The correlation between TSP and PM$_{10}$/PM$_{2.5}$ matched with the coefficient of determination being 0.8164/0.8376. In addition, a linear correlation existed between TSP and PM$_{10}$. A correlation analysis between PM$_{10}$ and PM$_{2.5}$ was also conducted, and the results indicated a strong high linear correlation between the two.

Management and Control Measures

Perfecting the construction dust pollution prevention and control management system: Laws and regulations and local stipulations have initially divided the power among various administrative departments concerned with construction dust pollution. However, due to the difference in

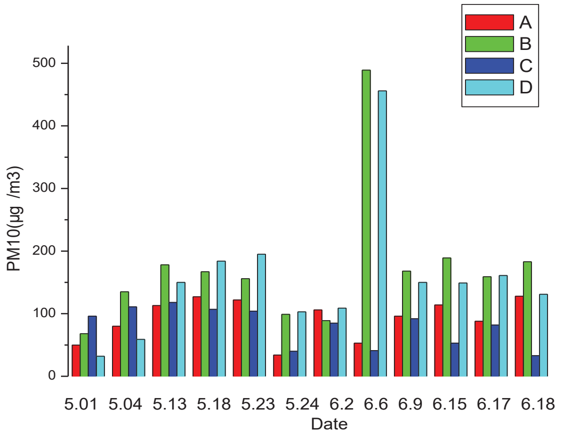

Fig. 2: PM$_{10}$ concentration distributions at the four monitoring points during the foundation excavation phase.

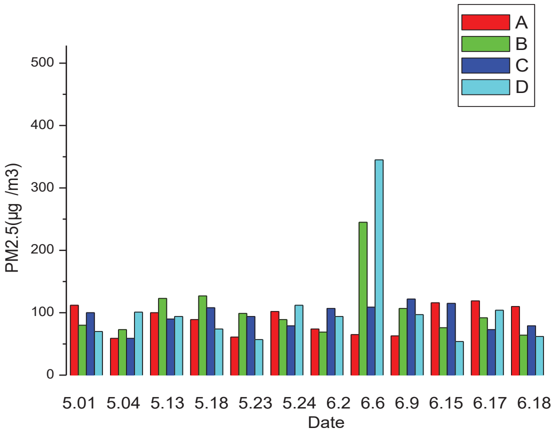

Fig. 3: PM$_{2.5}$ concentration distributions at the four monitoring points during the foundation excavation phase.

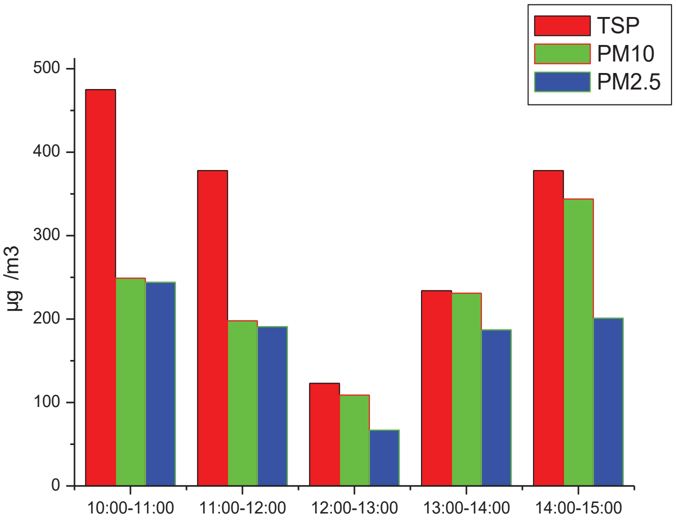

Fig. 4: Concentration change graph at point B on May 18.

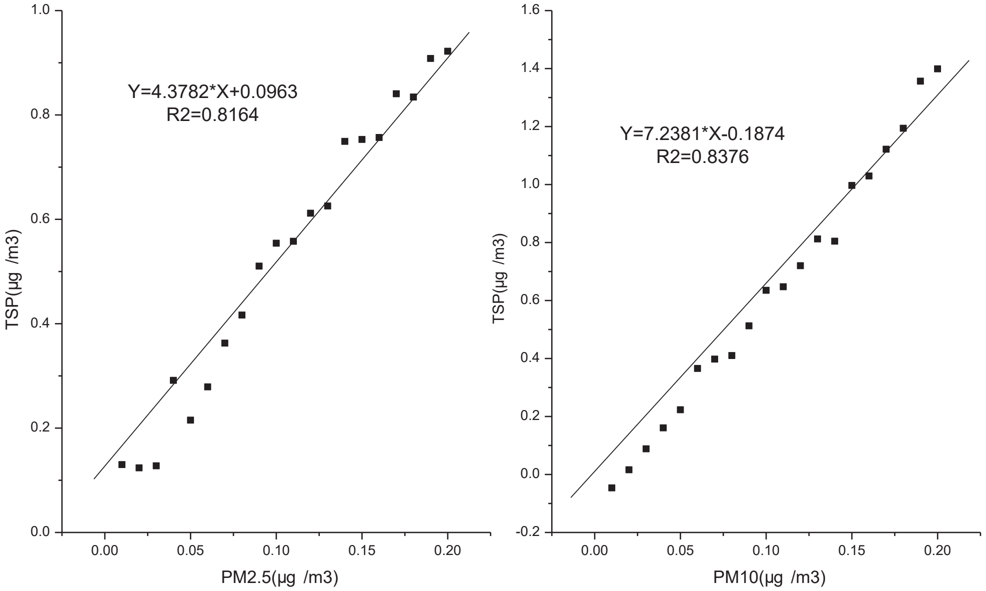

Fig. 5: Correlation analysis of TSP, PM_{10}, and $PM_{2.5}$.

time, regions, and related environment in actual operations, the power-crossing phenomenon can inevitably exist in the management process of the departments. For instance, urban management law enforcement department is usually involved in the demolition of existing buildings, and shantytown renovation management department is in charge with the demolition of buildings in shantytowns and villages in cities. Similarly, the competent administrative departments of land and resources are involved in the demolition of buildings with illegal use of land. Competent planning administrative departments handle the demolition of buildings that violate the planning process. In addition, city appearance administrative and transportation management departments are in charge of the transportation and demolition of residual building materials. To address these issues, a corresponding information sharing system and platform should be developed by assigning the environmental protection department as the leading organization and other related departments as constituent parts. Subsequently, the problems arising during the governance process and innovative opinions and suggestions must be discussed and summarized. This way, a strong coordination can be achieved among various departments, and construction dust pollution prevention and control problems can be efficiently solved.

Establishing a responsibility management mechanism for construction dust: To establish a responsibility management and assessment mechanism and form a system guided by the leader, the dust management and control systems and standards should be polished first. Related responsibilities and tasks should be executed according to these systems and standards. A management model that integrates dust control and safety construction should be developed, and full-scope supervision and assessment must be implemented to manage and control the entire process. The building construction project manager should serve as the principal of the entire project, develop the overall plans, and emphasize the importance of solving the dust pollution problem. Post managers should focus on and include dust management in the working range of the entire process management and control. They must also realize the corresponding managerial steps according to their own tasks and responsibilities. Group leaders should actively follow the command of the project department, manage dust pollution control, and construct an assessment mechanism to control dust pollution. Last, the project department head should sign a letter of responsibility with the other in-charge personnel to strengthen dust management and control.

Conducting comprehensive and refined construction dust management and control: The engineering project is divided into several areas, such as construction, living, and administrative areas. The construction area should be swept and watered by the structural unit to maintain cleanliness. Carrier vehicles must be washed to ensure a dust-free state. Other areas must also be cleaned. The keeper of the cement bunker, which is a critical control area, should take full responsibility for the area's cleaning work. Cement materials should be sealed using bags and separately stored from other materials. In addition, the cement bunker must be comprehensively sealed to ensure that the bunker is tidy. Additional attention should be paid to the transportation of construction wastes, which should be sealed before transporting using automatic flip vehicles. Any vehicle without such equipment should not be admitted to the site. Cargo deadweights must be controlled to ensure that the seal of the compartments does not have any gap. The automatic turnover process should also be gradually promoted to prevent the dust problem caused by any violent actions.

Promoting technological innovation for construction dust control: Some fences or sheds should be established before the formal architectural engineering construction. The immobility, stability, appearance and sealing state of the fence facilities must also be ensured. No fence situation or unsealed fence is allowed on the construction site. In addition, hardening treatment should be performed at the site's exits and entrances, trunk roads, material stacking area, office area, and living area with concretes. Daily cleaning work must be performed. Protective work should also be conducted at on-site material stacking areas. Moreover, some earthwork on the site should be covered or greened and solidified, depending on the building requirements and stipulations. Specific personnel should be assigned to clean and ensure the good state of construction vehicles running in and out of the site, especially those that transport sands, earthwork, and mucks, which should be shielded to guarantee air tightness and proper containment to prevent dust pollution (i.e., contents that can cause dust pollution are not exposed). Water carts, mist-spraying cannons, and other spray systems can be installed to perform dust removal work on the construction site. These systems are reliable means that can effectively reduce dust generation and realize dust pollution governance.

Improving environmental consciousness for construction dust management and control: To radically improve the environmental consciousness of construction personnel, the propaganda work of dust pollution governance should be strengthened to instill awareness on the destructive and harmful effects of dust pollution on air quality. The hazards and governance measures of dust pollution can be endorsed through related media so that people can be aware of the importance of dust governance. The guiding and supervisory roles of the media can be utilized to promote the effective implementation of urban building construction and dust pollution governance in China.

SUMMARY

With the continuous acceleration of economic development and urbanization progress in China, PM pollution has become a serious problem that influences the air quality in China. Moreover, PM concentration has become an important index that manifests atmospheric conditions. As the infrastructure construction in Zhengzhou continuously develops, dust pollution due to building construction is becoming increasingly severe, and construction dust is gradually becoming a major pollution source of atmospheric PMs. In this study, a typical building in Zhengzhou was taken as a case study to monitor the amounts of TSPs, PM_{10}, and $PM_{2.5}$ concentrations during the foundation excavation phase. The results show that the PM_{10} and $PM_{2.5}$ concentrations at the monitoring points in the downwind direction of the prevailing wind are generally higher than those in the upwind direction. The TSP concentration is constant at 250-500 μg/m^3 in most days, and the coefficient of determination between TSP and PM_{10}/$PM_{2.5}$ is 0.8164/0.8376. The emission reduction of building construction dust can be promoted by perfecting the construction dust pollution prevention and control system, establishing the responsibility management mechanism for construction dust, performing comprehensive and refined management and control of construction dust, facilitating technological innovation for building dust control, and improving the environmental consciousness on building dust management and control. In the future, an in-depth study should be conducted by polishing the analysis on the emission factors of building construction dust and performing periodic dust monitoring of the entire construction site. Differences among emission factors in various construction phases during different seasons must also be considered.

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