Research for Improvement of Environmental Management Efficiency in case of Dust Monitoring in Developing Country

Reiko Abe

Yamaguchi University
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for peace and health

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ABSTRACT

At construction sites, dust emitted during construction has been a serious problem for health and the environment. Because the impairment of lung function by dust pollution had become an un-ignorable issue after the 1980s in Japan, the use of powered air-purifying respirators and regular dust measurements by digital dust indicator (DDI) have been required by law at construction sites.

On the other hand, there is not enough awareness of health care at construction sites in developing countries despite a high demand for tunnel construction. To avoid serious health hazards, such as a case in Japan, the promotion of health awareness among workers and the prevalence of dust monitoring are fundamental. However dust measuring and monitoring by traditional techniques are expensive in these countries. Furthermore, the current dust measuring methods have other problems, such as time consumption for data calibration because of variable monitoring conditions.

The current status of the environmental specification/guideline in India, one of the developing countries, is mentioned. The specification/guideline of developed countries, including Japan, is mentioned for comparison. Actually, the specification/guideline for dust control is not specified for construction work in India at present. Additionally, the environmental requirements by government/authority are in confusion. Consequently, the environmental monitoring and control plan issued by the contractor is not effective for environmental improvement. The plan does not include the control/target value of dust concentration. The plan does not show the implementing action regarding dust control. The actual environmental condition is not improved at the construction site.

The project for dust monitoring using mobile phone was initiated at the Metro construction site in India by the JICA team. The purpose of the project is to improve the environmental condition. The actual environmental management was carried out based on dust monitoring. The environmental training was provided at the construction site. The above process shows the improvement of environmental management. As a key point, the technical transfer work is important to the client and contractor and will be continued. The workshop

regarding environmental management was held for representatives of the client, of the Indian government, and other Indian Metros.

The most important item is to apply the environmental management system at the site. After the JICA project, the contractor has applied the dust monitoring as required by the client at the construction site. The method statement for dust monitoring was issued by the contractor. Based on the measured dust concentration volume, dust masks are used at the construction site. The instruction regarding dust measuring and dust mask usage has been carried out by the contractor since August 2012.

The awareness campaign is effective for environmental management of construction work. The installation of sign boards, the distribution of pamphlets, and the exposition training were carried out. The awareness campaign is effect for improvement of environmental management at the Bangalore Metro Project.

Some real problems were apparent in the case of dust monitoring by mobile phone at the construction site of the Bangalore Metro Project. A dust monitoring system utilizing IP cameras was developed to solve such problems. The process of developing the monitoring system is shown in this study. The dust monitoring utilizing IP cameras will be applied at the construction site. Application of the IP camera monitoring system makes measuring easy for construction work. As the monitoring of dust concentration becomes standardized, the protection of health with dust masks will result in better environmental conditions in developing countries.

In this study, one process is shown for environmental improvement. For more improvement of environmental management, this study can support the establishment of a specification/guideline that is the same as in developed countries.

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Chapter 1
INTRODUCTION

1-1 Scope of study

At the underground construction site, dust emitted by construction has been a serious problem for health and the environment. Because the impairment of lung function by the accumulation of floating dust had become an un-ignorable issue after the 1980s in Japan, the use of powered air-purifying respirators and regular dust measurements by digital dust indicator (DDI) have been required by law at construction sites in Japan.[1]

On the other hand, there is not enough awareness of health care at construction sites in developing countries, despite a high demand for tunnel construction. To avoid serious health hazards, such as a case in Japan, the promotion of health awareness among workers and the prevalence of dust monitoring are fundamental. However, dust measuring and monitoring by traditional techniques is expensive in these countries. Furthermore, the current dust measuring methods present other problems, such as the time consumption for data calibration because of variable monitoring conditions (Photo 1-1).

Photo 1-1 Construction site of the Indian Metro Project

For improvement of environmental conditions, Shinji suggested a new dust monitoring method that utilized digital cameras to measure the dust concentration at construction sites[2]. This method is improved by introducing innovative techniques such as smart-phone cameras, because the performance of mobile phone cameras has improved extra significantly. In 2012, this dust monitoring system using mobile phone was implemented at the Indian Metro construction site[3]. Because the construction site was not underground, but an open cut tunnel construction under sunshine, the dust monitoring chassis box was developed to get flash pictures that are used for the internal processing to quantify the dust density.

The result of dust monitoring system using mobile phone shows that this method needs some improvement of sustained accuracy for long-term monitoring and a flexible calibration system for changing environmental conditions. The dust monitoring system usinig mobile phone is explained briefly, and then its problems are clarified. Dust monitoring by video image processing system and dust monitoring by IP camera[4] are presented as solutions to the problems mentioned above.

In this paper, the basic mechanism for dust monitoring is shown first. Secondly, the dust monitoring system using mobile phone is applied at the Indian Metro construction site. The results and problems are shown in the paper. Thirdly, the improved monitoring systems that employ video image processing and IP cameras are shown. As another point, the application and management for environment preservation are most important in the developing countries. The management system is also studied based on the environmental comparison of specifications between developing and developed countries (See Photo 1-2).

Photo 1-2 Drilling work at the Indian Metro construction site

1-2 Organization of chapters

This paper shows the structure of this study as below.

Chapter 1 INTRODUCTION

The scope and the purpose of the study are shown. It based on the previous study and current status for dust management.

Chapter 2 CURRENT STATUS OF ENVIRONMENTAL CONDITIONS AT THE CONSTRUCTION SITE

The specification/guideline for dust management in developed countries is described first. Secondly, the current status of environmental conditions in developing countries is described. Finally, the comparison between developed and developing countries is shown.

Chapter 3 CONSTRUCTION DUST MEASURING AND MONITORING BY USING MOBILE PHONE CAMERAS

The mechanism of dust monitoring system using mobile phone is explained first. It was applied at the construction site of the Metro Project. The question survey was carried out before and after the project regarding dust monitoring. The results are described in this chapter. Additionally, the problems are discussed, based on these results.

Chapter 4 DUST MONITORING BY IP CAMERA SYSTEM BASED ON VIDEO PROCESSING

The dust monitoring system using mobile phone is improved based on consideration of Chapter 3. The dust monitoring system the utilizes video processing is described first. Secondly, the dust monitoring by use of IP camera, based on video processing, is described.

Chapter 5 IMPROVEMENT AND SUGGESTIONS FOR ENVIRONMENTAL MANAGEMENT

The improvement and dust control are mentioned in this chapter. The suggestions for effective environmental management are based on the study of dust monitoring in Chapters 3 and 4.

Chapter 6 CONCLUSION

Total conclusions are mentioned, based on applied dust monitoring systems.

The organization chart of this study is shown in Figure 1-1.

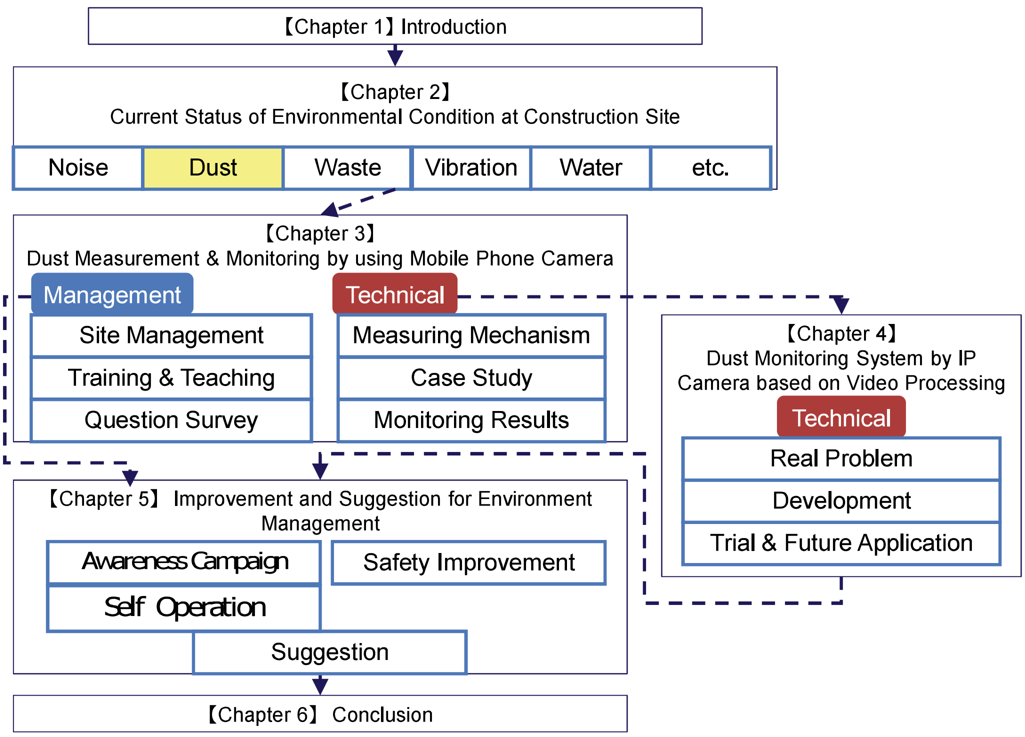

Figure 1-1 Organization chart of this study

In this introduction chapter, the actual problem in the case of the Indian Metro project and the scope of this study are highlighted as below.

Actual problem in the case of the Indian Metro Project

- No monitoring of dust concentration because of expense of dust detectors
- No site management for dust monitoring
- No specification regarding environmental condition, including dust monitoring for construction work

Scope of this study

- Applied dust monitoring at construction site by use of dust detectors with low cost and ease of handling
- Suitable site management to improve the environmental conditions based on dust monitoring
- Suggested specification/guideline regarding environmental conditions for construction work

Reference

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2) Ministry of Health, Labour and Welfare: Zuidou tou kensetsu kouji ni okeru funjin taisaku ni kansuru guideline, p.3, 2000, (in Japanese).

3) JAPAN INTERNATIONAL COOPERATION AGENCY: Special Assistance for Project Implementation (SAPI) – Appling the On Site Visualization and Dust Monitoring at Bangalore Metro Construction Sites – Final Report, 2012.

4) R. Abe, Y. Sasaki and M. Shinji: Dust Monitoring System by Network Camera on Video Processing, *Journal of Japan Society of Civil Engineers*, Ser.F1(Tunnel Engineering) Vol.70, No.1, pp.15-25, 2014, (in Japanese).

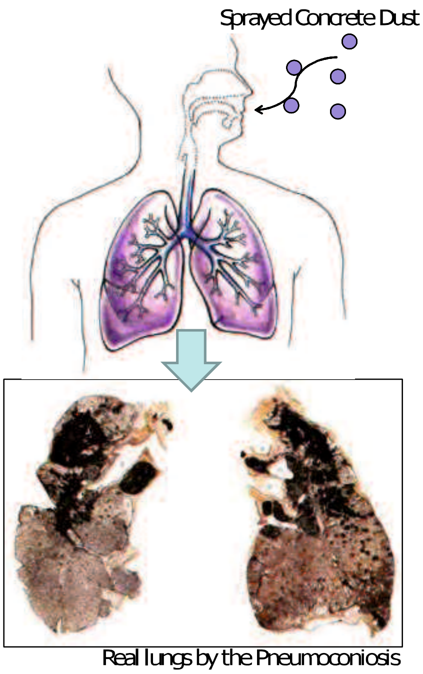
Chapter 2

CURRENT STATUS OF ENVIRONMENTAL CONDITIONS AT THE CONSTRUCTION SITE

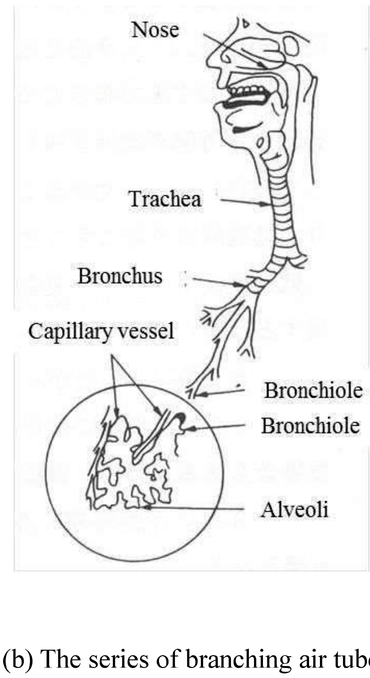
2-1 Why is dust monitoring necessary?

There are many types of dust particles existing in air, such as the exhaust from vehicles, gyrating dust on roads, wind-borne dust particles, volcanic ash, fume from factories, ash, and soot[1]. The long-term inhalation of these dust particles produces dysfunction pneumoconiosis, which is defined as "diseases consisting mainly of fibrotic changes in the lungs due to inhalation of dust" by the Pneumoconiosis Act in Japan, as shown in Figure 2-1a.

Figure 2-1b shows the parts of the respiratory system. Inhaled air moves to alveoli through the trachea, bronchus, and bronchiole, and the oxygen is absorbed into capillary vessels. In reverse, carbon dioxide is discharged into alveoli from capillary vessels.



(a) The pneumoconiosis



(b) The series of branching air tubes

Figure 2-1 The risk of the dust

A dust particle that is inhaled with air is attached to different places, depending on its size. Figure 2-2 shows the dust deposit rate for different parts of the body. Particles having a diameter of greater than 10 µm are deposited within the cavity of nose and throat and brought up with sputum. Most particles of approximately 5 µm are deposited in the upper respiratory airway passage and get into the throat by villous movement. Some particles are eliminated from the body by sputum, and others remain in the digestive system. However when the inhalation volume is excessive or there is a functional deterioration in villous, dust particles can reach the alveoli.[2] Dust particles that range in size from 1 to 2 µm are the most interactive and the cause of pneumoconiosis because of their high deposit rate within the lung. The deposit rate ceases with decreasing particle size, but increases again with particle size less than 0.4 µm.[3]

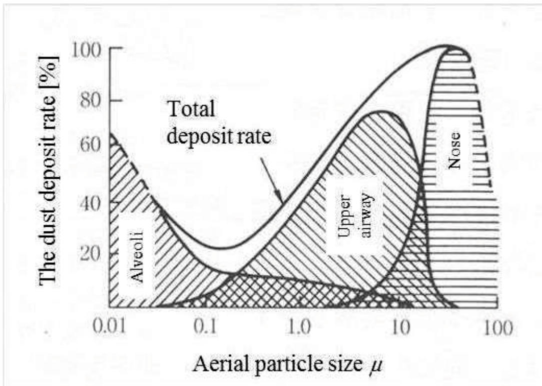


Figure 2-2 The dust deposit rate by different parts body[3]

Figure 2-3 shows the route of dust entry into the body. The hardly soluble dust particles in the alveoli enter the pulmonary interstitium by phagocyte and are deposited in the lymphatic gland. It creates fibrous nodules more than 0.5–1.0 mm size.[4] In addition, hardly soluble particles are not excreted easily from the body and accumulate within alveoli, which could result in a deleterious long-term effect. On the other hand, fusible dust particles are dissolved in capillary vessels and eliminated gradually after depositing in organs.

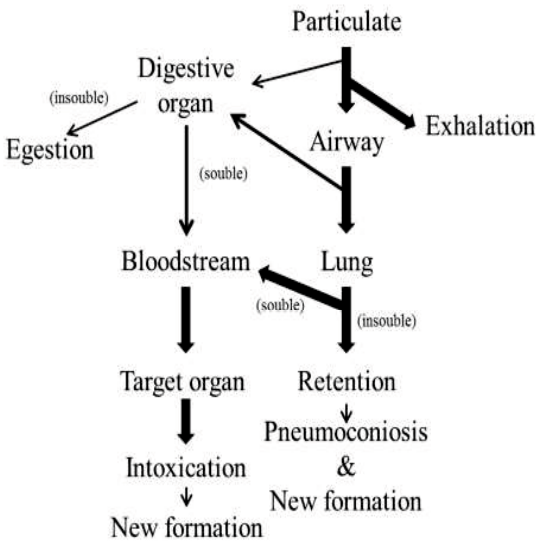


Figure 2-3 The route of dust entry[5]

In Japanese regulations, the following materials are defined as dust that can cause pneumoconiosis: soil, rock, minerals, abrasive, materials for glass and enamel, ceramic, cobbling, diatom earth, talc, clay, carbon, cement, aluminium, sand, dried sand, slag cement, ash, metallic spraying, arc welding, fly ash, and asbestos. The types of work that create mineral dust, such as pulverization, mesh control, input to roasters embarkation, packing, and scraping, are listed. Table 2-1 summarize types of pneumoconiosis caused by different inducing material. The amount of dust that enters the alveoli and can become a trigger of pneumoconiosis, which is called "inhalant dust", is used to measure the influence of dust on health. The type of inhalant dust and the relation to concentration are clarified by the Japan Society for Occupational Health. Table 2-2 shows tolerable dust concentrations. In the case of the dust containing more than 10% free silicon, the tolerable dust concentration is low, because free silicon has considerable harmful effects on health.[6]

Table 2-1 Type of pneumoconiosis[7]

Causative agent	Type of pneumoconiosis		Occurrences
Free silicic acid	Stoneman's disease	Typical	The workplace creates free silicic acid more than 30%, metal mine, mason, firebrick, glass factory etc.
		Atypical	The workplace creates free silicic acid more than 20%, casting, etc.
		Radical	Sandblast, silica stone smash, dust emission workplace etc.
Silicate compound	Lung asbestosis		Asbestos open, spinning, fabrication of asbestos cement sheets etc.
	Talc pneumoconiosis		Talc smash factory, rubber factory etc.
	Pyrophyllite pneumoconiosis		Crucible factory, etc.
	Diatomite pneumoconiosis		Diatomite factory and mining
Aluminium & Aluminium compound	Aluminum lung		Aluminum powder factory, etc.
	Alumina lung		Aluminum remanufacture and Aluminum production
Compounds of iron	Welding pneumoconiosis		Welding operation
	Sintered sulfide lung		Calcination hauling
	Pyrite pneumoconiosis		Sulfide mining, ammonium sulfate factory
Carbon	Graphitosis		Graphite factory, electrode factory, graphite mining
	Carbon lung		Ink factory and carbon black factory
	Activated coal lung		Activated coal factory
	Coal-miner's lung		Coal mine

Table 2-2 Tolerable dust concentration[8]

	Dust type	Tolerable concentration (mg/m³)	
		Inhalation dust*	Total dust**
Type 1 dust	Talc, mellite, aluminium, alumina, diatomite, mineral sulphide, bentonite, kaolinite, activated carbon, black smoke	0.5	2
Type 2 dust	Free silica acid, mineral dust, ferric oxide, carbon black, coal, zinc oxide, titanium dioxide, Portland cement, marble, absorption of dust, farina, cotton dust, wood powder, hide powder, cork powder, Bakelite	1	4
Type 3 dust	Lime stone ‡, other anorganic and organic substance	2	8

At a tunnel construction site in Japan, the pneumoconiosis is more serious than other industries, so that the dust measurement is particularly important. The dust measuring and monitoring have been reviewed in Japan because of the pneumoconiosis matter. However, the pneumoconiosis matter receives poor attention in developing countries in regard to the present status of construction sites (See Photo 2-1).

In this chapter, the current status regarding dust measuring and monitoring at construction sites is shown, with comparison of specifications between developed and developing countries.

Photo 2-1 Drilling and blasting work at the Indian Metro station site

2-2 Current status regarding dust measuring and monitoring at construction sites

2-2-1 The case of Japan

The disadvantage of tunnel work is that dust is emitted during almost the entire construction process. It caused serious problems for health and the environment, and then the impairment of lung function by dust pollution became an un-ignorable issue. As shown in Figure 2-4, the number of cases of impairment of lung function has been dramatically decreased by the installation of dust measuring devices and the improvement of excavation technique and ventilation systems. The risk of impairment of lung function, however, still remains at a considerable level because of the increasing dust emission from excavation sites.

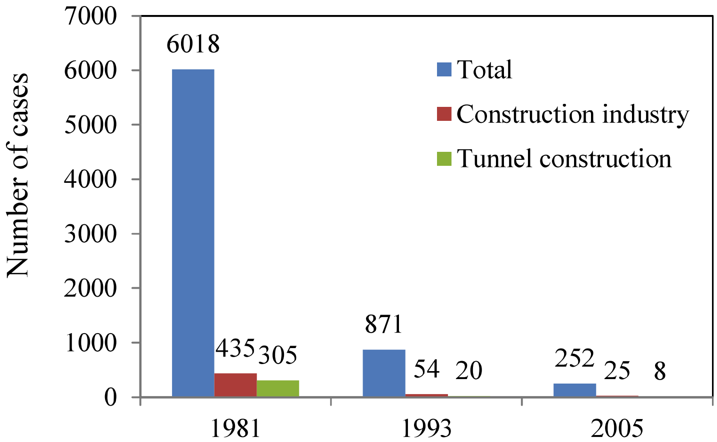


Figure 2-4 The industry-classified number of pneumoconiosis[9]

To improve this situation, the Ministry of Health, Labour and Welfare revised Ordinance on Prevention of Hazards Due to Dust Ministry of Labour Ordinance in 2007 and the use of proper ventilation equipment and powered air-purifying respirators and regular dust measurement by digital dust indicators are required at construction sites.[10] Also "the guide for the dust measurement at the construction work of tunnels" (2002), called just the "guideline," was amended and the target level of dust concentration was set below 3 mg/m^3 at the point 50 m from the tunnel face, measured by a digital dust indicator.[11]

Several measures are taken at tunnel construction sites to achieve this target level. For reduction or elimination of the amount of dust, the attention to dust sources, such as the consideration of material selection and the introduction of ventilation and dust collection equipment, have been encouraged. For example, the use of a dust reduction agent or coal ash for shotcrete mix is suggested and implemented at tunnel excavation sites. In addition, an electronic dust collection machine[12] and air curtain[13] are provided to prevent diffusion of dust, and the local ventilation system is installed to segregate and collect dust for treatment.[14] Furthermore, remote controlled concrete spraying machines and powered air-purifying respirators are introduced for the protection of workers.

2-2-2 The case of India

Dust is a generic term used to describe fine particles that are suspended in the atmosphere. Sources of dust emitted directly into the air are vegetation, burning of biomass, industrial and construction of activities, and windblown particles (Photo 2-2a and b). Dust can be defined in practical terms as anything, ranging in size from a few nanometer (nm) to a few micrometers (µm) in diameter, which can become suspended in the atmosphere. According to the British Standard Code, dust is defined as a solid particulate matter (PM) 1 to 75 µm in diameter[15].

(a) An Indian city (b) Bangalore

Photo 2-2 Heavy traffic conditions in Indian cities

Dust can be particles that are emitted directly and secondary particles that are formed by chemical processes in atmosphere Particle size is an important factor influencing the dispersion and transport of dust in the atmosphere and its effects on human health. Particles less than 10 µm in diameter, known as PM_{10}, are often inhalable, whereas particles less than 2.5 µm, known as $PM_{2.5}$, are considered irrespirable. Particle size less than 10 µm can cause concern about health effects, whereas particles greater than 10 µm are associated with public perception and nuisance.[16] PM_{10} is of more concern to human health because the particle can enter the lungs, causing breathing and respiratory problems, with long-term health effects dominated by cardiovascular disease and mortality. These particles also carry adhered carcinogenic compounds into the lungs[17] (See Photo 2-3).

Photo 2-3 Bangalore city on dust condition

Construction dust is direct particulate matter that is emitted because of construction work on the ground and is a big problem for health and the environment. In India, there is a regulation that dust concentration during construction must be less than 2.5 mg/m^3. [18] However, dust measuring, monitoring, and countermeasures have not been properly implemented so far, because dust measurement is expensive. In India, the construction segment is the second largest employer next to agriculture, and it employs approximately 10 million people. The annual turnover of the construction industry is more than 6% of the national GDP. The construction segment is one of the most vulnerable segments in terms of safety and health-related incidents in comparison with the other sectors. Several research and engineering techniques have been developed to provide dust monitoring measures at construction sites.

Where particulate matter is considered to be the main ambient air pollutant, two dust fractions are commonly used in monitoring programs, the PM_{10} and the $PM_{2.5}$. The PM_{10} includes particles with an aerodynamic diameter up to 10 µm and $PM_{2.5}$ represents particles with an aerodynamic diameter up to 2.5 µm. Aerodynamic diameter is defined as the diameter of a hypothetical sphere of density 1 g/cm^3 having the same terminal velocity in calm air as the particle in question, regardless of its geometric size, shape, and true density.

The four main categories of dust are generated dust, total suspended dust, nuisance dust, and fugitive dust nuisance.[16] The scope of this study is measuring and monitoring of construction dust that is generated by various activities at construction sites. To evaluate the impact of dust on human health because of exposure to the dust or to investigate the effectiveness of dust control measures, one must have a method or methods for the evaluation of dustiness. In this section, various dust measuring and monitoring methods have been reviewed. Many methods to measure the dustiness at construction sites have been reported in the literature, mainly particle mass based methods, particle count methods, particle light scattering methods, and particle light absorption methods, utilizing measurements of mobility, chemical components, and precursor gases. Particle count methods were developed to test air as it enters and exits filters. Filter efficiency is the ratio of particles trapped by the filter to the total number of particles found in the air upstream of the filter. Mass concentration methods, the simplest of the dust measuring methods, determine the total weight of dust collected in a given volume of air. In gravimetric methods, air passes through the instrument at a desirable rate of 2.5 litter/min under the action of a diaphragm pump. Modern photometric (light-scattering) methods have the major advantage of the addition of electronic circuitry that permits a combination of immediate readout and integration over any chosen time interval. Hence, they can be employed for both short-term and long-term sampling.

2-3 Specification regarding dust measuring and monitoring in developed countries

2-3-1 Japanese and Europe specification

Firstly, the specification applied by Japan for dust measuring and monitoring is mentioned. The specification applied by Norway is mentioned as another comparison. The trend and basic requirement in developed countries are shown in this section.

Guideline – Dust monitoring specification in Japan[19]

(1) Abstract

The Japan Construction Occupational Safety and Health Association conducted survey research on the dust the measurement methods at tunnel construction sites, the state of the implementation of measures such as ventilation and sprinklers, and the tunnel construction condition, as well as collecting the information about dust measurement methods in tunnel construction sites and the basis of effective dust abatement measures at tunnel construction sites. Furthermore, the educational materials for the ventilation concept in tunnel construction sites and proper usage of mask were introduced by the Research Committee for Effective Ventilation Techniques in Tunnel Construction Sites during 1998–1999.

(2) Introduction

The purpose of this Japanese guideline is to secure the safety and health of workers in tunnel construction sites, as well as to dilute and to remove such hazards as gas dust, and exhaust fumes from excavations, dispose of piles of debris, and apply shotcrete to facilitate the establishment of comfortable working environments, by the establishment of standards for dust concentration.

This guideline also shows the standard method to measure the dust concentration for confirmation of the efficacy of provisions such as ventilation to implement in an effective and efficient manner. In this section, the dust measuring and monitoring is abstracted from this guide as shown below. Additionally, the suitable selection, use, and storage of respiratory protective equipment are presented specifically to secure the operators health as well as to prevent disaster in Japan.

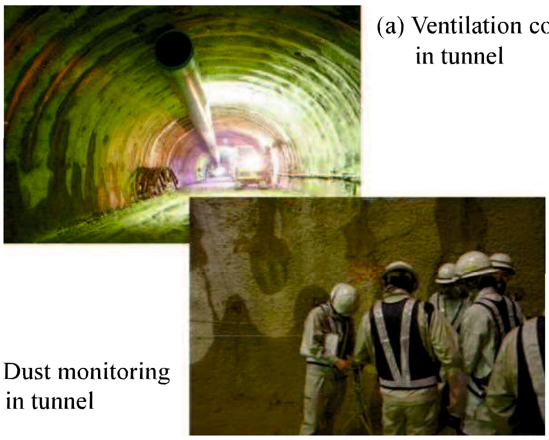
(3) Guideline for dust measuring and monitoring

This guideline revises "the technical guide for ventilation at the construction work of tunnels-design and dust measurement" (2002) and is called "the guide for the dust measurement at the construction work of tunnels" (2002), with the latest ventilation techniques.

Because dust amount differs for the size and type of tunnel, the excavation conditions, and the kind of the work, uniform measurement shall not be applied to all the cases. Further, the new measures are required for the maintenance of the working environment in the tunnels because of the introduction of large machines with diesel engines, which create more hazardous gas and dust.

In "the guideline for the dust measurement at the construction work of tunnels" (2002), the formulation of a dust measurement plan is defined as a determination of standardized limit of dust concentration in advance, and the measures are required when dust concentration is above the limit at the point of 50 m from the tunnel face to improve the work environment. The standardized limit of dust concentration is determined as 3 mg/m^3 (inhalable dust) based on the site condition and the technical potential for improvement of the work environment (Photo 2-4a) It also mentions that "In the case of the small face tunnel, where the criteria 3 mg/m^3 is hard to accomplish, the standardized limit should be set as low as possible." On March 1, 2008, the guideline was revised as "In the case of the small face tunnel, where the appropriate diameter and the number of ventilation tubing and the dust collection equipment are not be able to be installed to achieve the criteria 3 mg/m^3, the standardized limit should be set as low as possible, and the data must be recorded."

As "The measurement of dust concentration to confirm the efficacy of the countermeasures such as ventilation," the specific procedures, such as measurement plan that includes timing, position, and duration, as well as the measurement and evaluation method for dust concentration, wind velocity, and air volume are presented (See Photo 2-4b).



(a) Ventilation condition in tunnel

(b) Dust monitoring in tunnel

Photo 2-4 Tunnel site in Japan

As "The use of respiratory protective equipment," the appropriate method of selection, use, maintenance, and check for the contact is presented specifically. As "Health and Safety Education," the specific content and method of special education for the workplace, dealing with dust and the appropriate use of masks, are presented.

(4) Formulation of a dust accident prevention plan

Before the tunnel construction work, a dust accident prevention plan, including dust control machines, ventilation system, dust measurement to ascertain the efficiency of ventilation, respiratory protective devices, and industrial health education, should be formulated.

Photo 2-5 With fan mask in Japan[19]

Because dust generation status varies, depending on the size of the tunnel, excavation method, the ground condition, the operation process, the condition of operation, and the dust generation situation, the appropriate, comprehensive, and reliable measurement should be taken.Therefore, this guideline suggests formulating a dust accident prevention plan in advance.

In addition, "target level of dust concentration" is set to ascertain the efficiency of the measurement utilizing the dust control machines and ventilation system. A dust accident prevention plan should be formulated to achieve the target level of dust concentration, which is decided in advance (See Photo 2-5 and Figure 2-5).

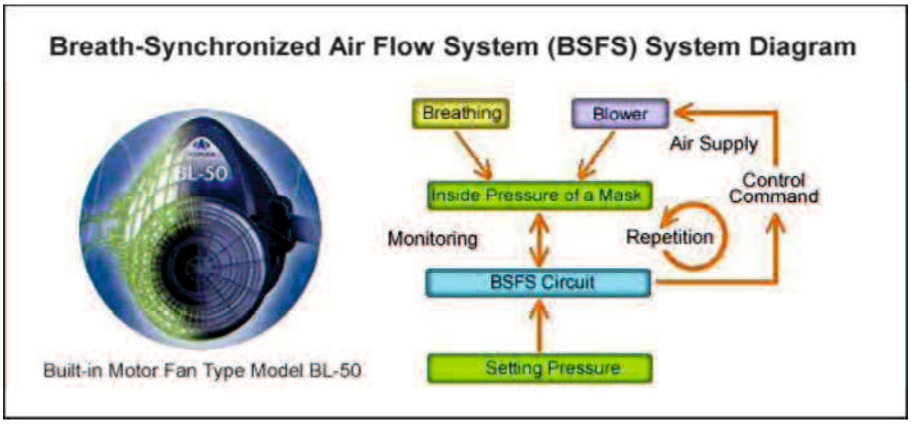


Figure 2-5 Fan mask mechanism[19]

Guideline – Health and safety in Norwegian tunnelling[21]

(1) Abstract

The general tendency in Norwegian tunnelling and other underground construction work during the past 10–15 years is improved safety, whereas improved health could not be observed. The health aspect is a challenge that must be given increased attention. All types of rock blasting work, including tunnelling and mining, have a high injury rate with a high severity factor (See Figure 2-6). Demand for reduced construction times increases the production intensity. The amount of air pollutants produced per time unit is increasing as well. Countermeasures put into effect have positively influenced the exposure and safety situation for the worker. Examples are new ventilation methods, better blasting agents and technology, cleaner diesel engines and fuels, and general acceptance of the importance of systematic health and safety work. There are still challenges concerning the work environment, especially the chemical and physical factors, such as mineral dust, gases, noise, vibrations, and lighting. Today, much attention is given to health damage caused by diesel waste gas (exhaust), but the exposure to mineral dust is also in focus.

Figure 2-6 Exposure to pollutants[21]

(2) Introduction

Tunnelling, mining, and other underground work have always been seen as a tough trade. Dust, gases from diesel engines and blasting, soot, oil mist, noise and vibration, radon and radon daughters, different chemicals, rock falls, temperature and air humidity, uncomfortable working positions, reduced light and visibility, danger of explosion, and traffic accidents are typical, and put a heavy burden on the workers. Increased mechanization and automation have reduced the physical loads but have increased the psychological stress.

The environmental precondition and requirements for tunnelling, mining, and other work are continuously made stricter. Regulation issued during recent years increasingly set stricter tangents for the general environment, as well as the external environment, stricter administrative norms for allowable concentrations of pollutants in the air, and more rigorous rules and regulations linked to procedures, methods, and equipment. Simultaneously the mass media, environmentalists, action groups, and others continually focus on factors that may influence the neighbourhood and the environment.

Transfer of knowledge and the understanding of new information are crucial factors for the development of a before work environment aimed at improving the health situation. This need applies to environmental loads linked to blasting/explosive, fuel/diesel oil, rock types/mineralogy, dust, gas, chemicals, noise, water, temperature, radiation, and others. Effects resulting from combinations of materials that affect people and the environment must be put into focus, and relevant criteria and procedures for controlling/monitoring releases into air, soil, and water must be established. This requirement also includes grouting materials. These materials must be safe to handle and use under the prevailing conditions that include possible contamination.

(3) Experience with the work environment

The work environment is usually described as physical and chemical environmental factors on one side and psychical and social factors on the other. There can be considerable differences as to how individual employees experience their own work situation and work environment. The experienced risk is often different from the actual risk.

The general development in tunnelling over the past decades has, in many ways, positively affected health, safety, and environment (HSE). This positive change includes increased interest and improved attitude and motivation for HSE work. The understanding of the relation between production work and HSE has improved. Further, the legal responsibility of top-level management has been made clearer and more transparent.

Improved explosives, blasting agents, and blasting techniques, more effective watering of the muck-pile, increased use of electric energy, cleaner engines and fuel, more systematic service and maintenance of equipment and roadways, and more effective ventilation methods are all useful factors in improving the air quality underground. These efforts also affect productivity and the economy in a positive way. Training and control functions are improved. A motivated and determined management is necessary for this development.

Analyses of sick leave and rehabilitation efforts have, in recent years, improved the understanding of health problems and methods to reduce the problems. Measurements of work hygiene and product development in relation to protective equipment are important key factors in preventing illness and personal injuries at work.

(4) Work environment and measures

The stimulation to a greater degree of technical and medical cooperation aimed at more purposeful and cost-saving supervision and inspection procedures, both regarding prevention technique and health services, will contribute to an improvement of the work environment in line with the society's general expectations.

Because of the demand for reducing construction time for tunnel projects, dealt with by increased mechanization and productivity , the amount of air pollutants produced per time unit is increasing. If the right measures are not taken, the air quality underground may be dramatically worsened and the workers highly exposed to a variety of airborne substances (See Photo 2-6).

Photo 2-6 Placement of sampling equipment on operator[21]

With reference to the work environment generally, the chemical and physical factors such as dust, gas, noise, vibrations, and lighting are very similar in the construction and mining industries. On the other hand, conditions related to psychological pressure or stress can be rather more dominating in construction activities (tunnelling) than is usually the case in mining. This difference has been confirmed in discussions with employees with experience from both the construction and the mining industries.

Tight construction schedules cause an increasing amount of work to be executed simultaneously behind the tunnel face. This condition may significantly worsen the air quality and the work environment related to residual materials. When bolt hole drilling for permanent rock support, concrete and carpentry work, cleaning of footings, infilling of roadway sub-base, trench digging, piping works, and drainage take place concurrently with excavation activities, it is obvious that reduced air quality and worsened general safety may easily result. Particularly, activity in the completion phase can cause a “pile-up” of site clearance work, including the removal of rubbish, literally giving a “messy” work situation.

The work environment and air quality at the tunnel face is only slightly affected by increased activity behind the face. To obtain an acceptable work environment for the tunnel as a whole, the working patterns in the tunnel should therefore attempt to eliminate or even out the environmentally harmful activities over the building period as a whole, and also over the shifts during the day.

(5) Chemical and physical parameters – particle pollution

Despite the introduction of dust-damping efforts and ventilation, particle pollution (mineral dust, organic particles such as soot and oil mist) is a dominating air polluting environmental factor in rock-blasting work. Investigations show occurrences of illness from dust in the lungs (reduced lung function and lung diseases, among others silicosis). Since the early 1970s, testing and documentation of dust and other air pollutant have been carried out. This effort includes sampling of dust, with measurements of quartz content and types of particles. The objectives have been both a documentation of the level of exposure to dust for individual workers and determination of the background level in different work situations and areas.

Investigations show that the threshold limit values (TLV) are reached more frequently in tunnelling than in mining. This development is especially linked to differences in the quartz content in the dust, but it is also linked to the fact that the work intensity in tunnelling operations often is higher than in mining.

The content of alpha-quartz in the dust from the tunnels varies from 0% to more than 50%. Investigations indicate that the danger of silicosis must still be regarded as real in a number of tunnelling situations. Therefore, it is necessary to use available knowledge and information to check and apply preventative efforts, together with regular and proper health supervision of the employees. The TLV for rock dust depends on the quartz content as shown in Figure 2-7.

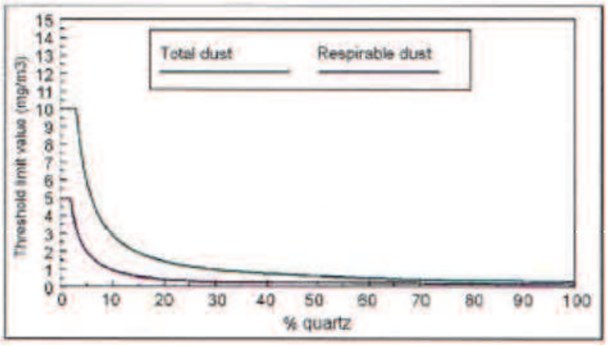


Figure 2-7 The relation between TLV and the quarts content in dust[21]

Based on the above principal, the "administrative norms," which represents limits for acceptable concentrations of gas, dust, and fumes are determined by the Directorate of Labour Inspection. The norms are set from medical, technical, and economical evaluations. An overview is given in Table 2-3.

Table 2-3 Norwegian administrative norms for acceptable concentrations[20]

Substance	ppm	mg/m³
CO carbon monoxide	25	29
CO_2 carbon dioxide	5000	9000
SO_2 sulphur dioxide	2	5
NO_2 nitrogen dioxide	2	3.6
NO nitrogen oxide	25	30
NH_3 ammonium	25	18
Nitroglycerin	0.03	0.27
Formaldehydes	0.5	0.6
Dust: total dust (all dust < 10µm) respirable dust (75% of all dust < 5µm)		 10 5

The limits are normally given as the highest acceptable average concentration over an 8-hour work shift. Higher concentrations are allowed as short-time peak values (aggregate time with high concentration less than 15 minutes per shift), if compensated by lower concentrations during the rest of the shift.

(6) Developments and possible future problem areas

In the following, a summary is given of a number of other relations that are important, or will become of importance, for HSE work:

- HSE work must be become an activity with equal priority as planning, progress, and economy.
- HSE “Safety Delegates” are an important and positive resource. They must be better utilized.
- More information on the use service value and limitations for various types of protective equipment, e.g., personal protective equipment against gases, dust, noise.
- Methods for control, monitoring, and sampling vary greatly in frequency, content, and quality relating to both medical and exposure research studies. Gas and dust monitoring instruments give different results with parallel measurements. Different types of spirometers/lung function meters may give different volumes with poor quality assurance and lack of meaningful calibration. Different procedures for spirometry, standing or sitting, will give different results, as may different software for the calculation of results from lung function measurement. Equipment and procedures must be homogenous and harmonized, including calibration routines for both medical and technical monitoring.
- Concrete spraying and grouting work are very demanding work operations underground. Use of protective equipment and optimization of operations must be improved.

The industry is confronted with many difficult and challenging HSE tasks linked to underground work. However, the industry has competent workers and leaders who will ensure that the laws and regulations required for conforming to the environmental standard will be complied with through a collective and responsible effort.

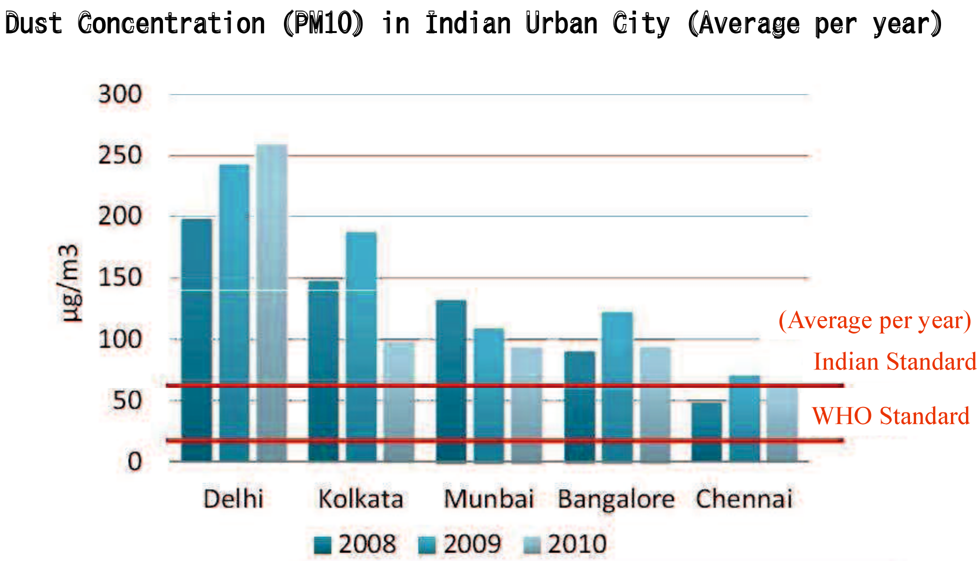
2-4 Specification regarding dust measuring and monitoring in developing countries

"The Air Prevention and Control of Pollution Act" was established on 1981 as the first environment guide in India. However, there is no specification regarding dust control for construction work at present. The Indian government has paid attention regarding the environment because of air pollution in India's large cities. The Specification National Ambient Air Quality Standards (NAAQS) regarding air pollution was issued on 2009. The NAAQS is shown at Table 2-4.

Table 2-4 Environmental specification in India (NAAQS 2009)

Pollution Size		Indian Standard	WHO Standard
PM 10	Average per year	60μg/m^3	20μg/m^3
	Average per day	100μg/m^3	50μg/m^3
PM 2.5	Average per year	40μg/m^3	10μg/m^3
	Average per day	60μg/m^3	25μg/m^3

The limitation value of the Indian specification shows two to three times that of the World Health Organization. The current status and limitation value are shown in Figure 2-8.



Reference : Central Pollution Control Board (CPCB) (2011-2012)

Figure 2-8 Concentration of PM10 in Indian cities per year[18]

2-5 Comparison of specification and application for construction work between developed and developing countries

The comparison of administrative norms between developed and developing countries is shown in Table 2-5. In Table 2-5, Japanese and Norwegian specifications are mentioned as developed countries and the Indian specification is mentioned as a developing county.

Table 2-5 Comparison of administrative norms between developed and developing countries

	Air pollution		Construction site	Remarks
	PM2.5	PM10		
Developed Country (Japan)	35µg/m^3 *1)	10µg/m^3 *1)	less than 3 mg/m^3	
Developed Country (Norway)	25µg/m^3 *2) *3)	40µg/m^3 *2) *3)	10 mg/m^3	total dust (all dust < 10µm)
			5 mg/m^3	respirable dust (75% of all dust < 5µm)
WHO	25µg/m^3 *1)	50µg/m^3 *1)	–	
Developping Country (India)	60µg/m^3 *1)	100µg/m^3 *1)	No specification	

*1) Average per day
*2) Average per year
*3) Standard value by EU

As shown in Table 2-5, the administrative norms for construction work are not specified in India.

The actual applicable condition is completely different between developed and developing countries. A high risk exists in developing countries because of a lack of appreciation regarding pneumoconiosis.

Air control is required for construction works in India. The requirement by the client of Indian Metro Project is shown below.[22]

Client Requirements except from "Conditions of Contract on Safety, Health and Environment" Chapter - AIR MONITORING

- Construction activities that will generate dust impacts include excavation (including related activities), material handling and stockpiling, vehicular movement, and wind erosion of unpaved work areas.
- The impact of fugitive dust on ambient air pollution depends on the quantity generated, as well as the drift potential of the dust particles injected into the atmosphere. Large dust particles will settle out near the source and smaller particles are likely to undergo dispersal over greater distance from the sources and impeded settling. SPM levels will be monitored to evaluate the dust impact during the construction phase of the Project.
- The Air Quality Monitoring and Control Plan (AMCP) in contract-specific Site Environmental Plan prepared by the Contractor shall establish procedures to monitor impact air quality and measures to control air pollution including dust suppression due to construction activities at work sites. This plan shall contain description of activities that will cause degradation in air quality, environmental procedures to manage pollutants to minimize the air pollution, monitoring program, record keeping and reporting.

"Environmental Monitoring and Control Plan," including the Air Quality Monitoring and Control Plan has been issued by the contractor as environmental manager before commencement of construction work. The plan shows dust control and air emission as an actual action plan by the contractor as below.[23] For reference, the plan is attached in Appendix-1.

Control of Dust & Air Emission except from "Environmental Monitoring and Control Plan – Air Quality"

- Using proper equipment shall control air emissions & machines equipment maintenance should be carried out at regular interval.
- Every day morning before the site operation starts sprinkle water to the entire site.
- While transferring the fine aggregate/metal in dumpers make it sure that it is covered with tarpaulins in order to control the dust and maintain free board at least 300 mm.
- The point where the cement is transferred or mixer shall be covered with Gunny bags or plastic sheet in order to prevent the accumulation of cement dust particles.
- While sprinkling the water, the quantity of water used should not exceed that what is required to control the dust and the concerned person should make it sure that the water used should not affect the Housekeeping of site.
- The Engineers working at site & Safety personnel should make it sure that the sprinkling is done in a proper manner.

- Every two hours this cycle should be continued so that dust can be under control.
- If possible landscaping should be carried out with minimum cost since grass can prevent dust. This can be practiced looking into the soil conditions of the site.
- Sprinkle water on top of the metal/coarse aggregated which will also help in settling the dust while transferring metal for concreting/ batching Site/Plant/crusher.
- The approach road to the site can also be watered using sprinkler system to reduce the dust.
- The top of the fine aggregate/sand can be sprinkled with water in a mild way to ring down the dust under control.

The monitoring method/procedure with the trigger value of dust concentration and the countermeasure items for protection against pneumoconiosis are not specified for construction work at present in India (Photo 2-7).

Photo 2-7 Environmental condition at a construction site in India

2-6 The application to improve the environmental condition in developing countries

Dust monitoring is required based on the specification/guideline for preventive action regarding health protection at the construction site. However, it is not adequate to use the monitoring method and apply the specification from developed countries. At first, the suitable monitoring method, including monitoring equipment, shall be selected for easy control and low-cost performance to adjust the site condition. Secondly, the site environmental management shall be established to instruct engineers and train the workers. The most important point is to adjust the site condition. In addition, explanation and demonstration on the client side are required to expand the use of environmental control. As the effective action regarding environmental improvement, the awareness campaign is shown in this paper.

The principal procedure for environmental improvement is shown in Figure 2-9. The dust monitoring and site management is suggested as a partial example for environmental improvement.

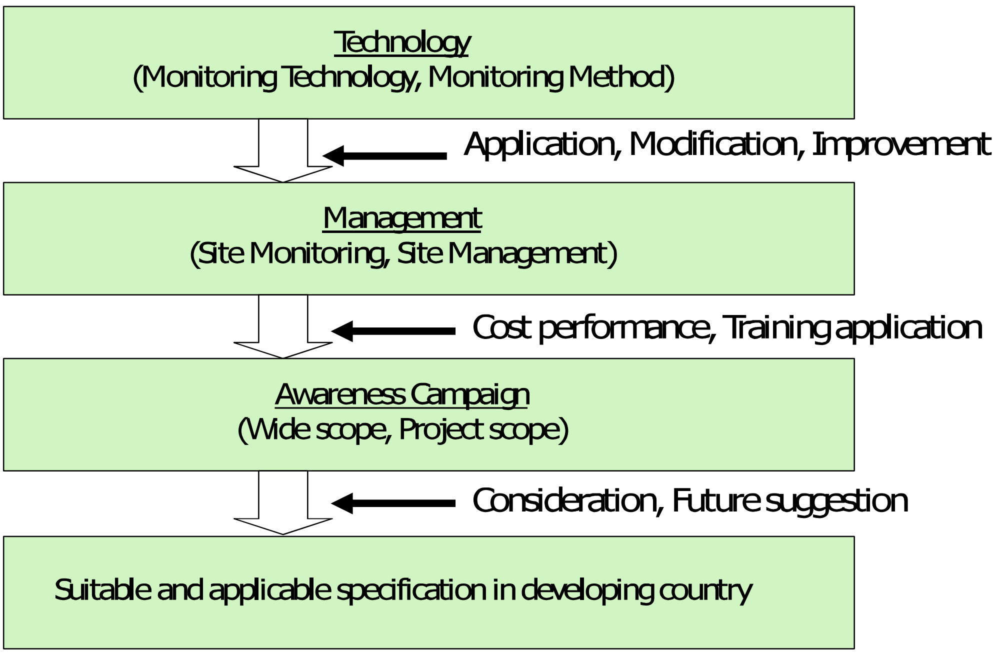


Figure 2-9 Principal procedure for environmental improvement

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Chapter 3

DUST MEASURING AND MONITORING BY USING MOBILE PHONE CAMERAS

3-1 Background

Dust is a generic term used to describe fine particles that are suspended in the atmosphere. Sources of dust emitted directly into the air are vegetation, burning of biomass, industrial and construction of activities, and windblown particles. Dust can be defined in practical terms as anything, ranging in size from a few nanometres (nm) to a few micrometres (μm) in diameter, which can become suspended in the atmosphere. According to the British Standard Code, dust is defined as a solid particulate matter (PM) 1 to 75 μm in diameter (BS 6069-2). Dust can be particles that are emitted directly and secondary particles that are formed by chemical processes in the atmosphere. Particle size is an important factor influencing the dispersion and transport of dust in the atmosphere and its effects on human health. Particles less than 10 μm in diameter, known as PM_{10}, are often inhalable, whereas particles less than 2.5 μm, known as $PM_{2.5}$, are considered respirable. Particle size less than 10 μm can cause concern about health effects, whereas particles greater than 10 μm are associated with public perception and nuisance.[1] PM_{10} is of more concern to human health because the particles can enter the lungs, causing breathing and respiratory problems, with long-term health effects dominated by cardiovascular disease and mortality. These particles also carry adhered carcinogenic compounds into the lungs.[2] A comparison between particle sizes is shown in Figure 3-1.

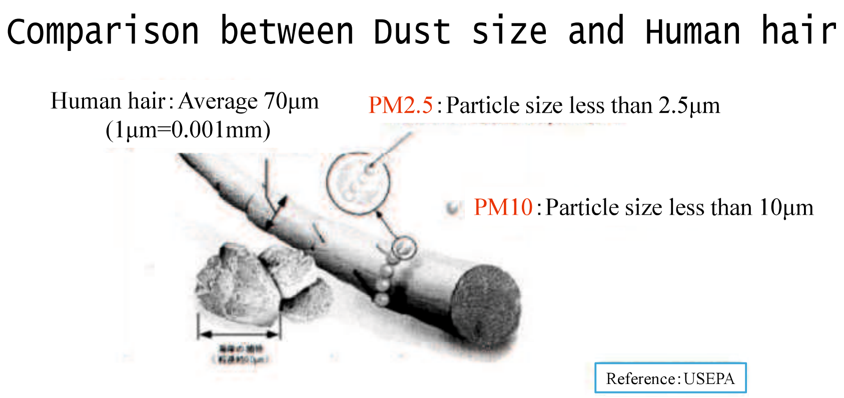


Figure 3-1 The comparison between particle sizes (PM10, PM2.5)[1]

Construction dust is direct particulate matter that is emitted because of construction work on the ground and is a considerable problem for health and the environment. In India, there is a regulation that dust concentration during construction must be less than 2.5 mg/m[3]. However, dust measuring, monitoring, and countermeasures have not been properly implemented so far, because dust measurement is expensive. In India, the construction segment is the second largest employer next to agriculture, and it employs approximately 10 million people. The annual turnover of the construction industry is more than 6% of the national GDP. The construction segment is one of the most vulnerable segments in terms of safety and health-related incidents in comparison with the other sectors. Disease and fatality rates are significantly increasing because of improper monitoring at construction sites. Therefore, safety and health consciousness should be comprehensively addressed.

Several research and engineering techniques have been developed to provide dust monitoring measures at construction sites. Recently, at construction sites in Japan, digital camera-based methods for dust measuring were introduced. These methods have been further improved by introducing innovative techniques that utilise mobile phone cameras, because the performance of mobile phone cameras has improved significantly. Shinji[2] initially developed a handy and quick dust monitoring method by using mobile phone camera techniques to measure the dust concentration at construction sites. In this method, a mobile phone camera, instead of a digital camera, is used to take a flash picture and calculate dust concentration immediately. This new method is more economical, easy to perform, and has a high correlation with digital dust indicators (DDI).

3-2 Introduction

The objective of this study is to investigate the implementation of a mobile phone camera-based dust measuring technique to plan and execute the dust management system at a construction site. This case study was carried out at the Bangalore Metro Project and funded by the Japan International Cooperation Agency (JICA) as Special Assistance for Project Implementation (SAPI).[3] The developed methodology was implemented for monitoring at the Bangalore Metro Station (Photo 3-1). This method was found to be quite useful to the workers at the construction site, who took precautions based on the levels of dust concentrations. The mobile monitoring system was calibrated and validated against the traditional DDI method to assure statistical validity. The result of this measurement was also displayed on a colour panel at the construction site, so that workers could take required precautions accordingly.

In this chapter, the mechanism and site application and management regarding dust monitoring system using mobile phone is shown.

(a) Site view

(b) Drilling work

Photo 3-1 Construction site with dust at the Bangalore Metro Project

3-3 Dust measuring mechanism

3-3-1 Use of flash photography

Smartphone

For dust measurement, an Android smartphone with camera and flash is used for taking flash photos, and the Android OS is used for image processing and calculating dust concentration. In this study, the HTC Desire HD phone by HTC Corporation was selected. It has dual LED flash near the camera lens, which is able to capture scattering light from the dust particles. Figure 3-2 shows the HTC Desire HD, and Table 3-1 lists its specification.

Figure 3-2 HTC Desire HD phone

Table 3-1 HTC Desire HD specification

	HTC Desire HD
Camera resolution	8-megapixel
Flash	Dual LED flash
White balance	Fixed

Black panel

A matt black sprayed panel is used as a background for the flash photographs to pick up the dust particles, as shown in Photo 3-2. The size of the panel is wider than the photo area, and the panel is sprayed with the matt black colour to reduce reflected light. Considering the reflected light influence, the distance between the black panel and the smartphone is set at 1.5 m. Table 3-2 shows the specifications of the panel.

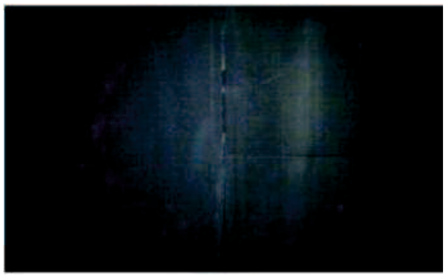
Photo 3-2 Black panel installation

Table 3-2 Black panel specification

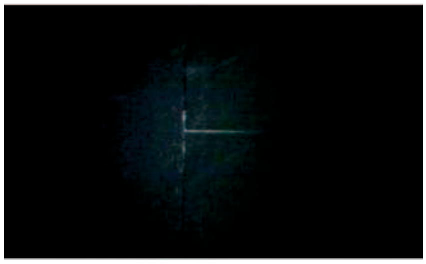
Size	0.6 x 1.2m
Material	Polystyrene foam
Coating material	Water-based emulsion black (matt)

Flash photographs

Figure 3-3 reveals the comparison of flash photographs and the measurement data by DDI. The photographs become brighter with increasing dust concentration.



Dust concentration 0.8mg/m^3



Dust concentration 2.8mg/m^3

Dust concentration 5.0mg/m^3

Dust concentration 6.2mg/m^3

Dust concentration 8.4mg/m^3

Dust concentration 9.4mg/m^3

Figure 3-3 Flash photographs of dust concentrations

The DDI was installed 1.3 m above the floor and 50 m away from the tunnel face, as described in the guidelines. The photographs were taken near the indicator and were synchronised with the data obtained by the indicator every minute. The accuracy of the indicator is shown in Table 3-3.

Table 3-3 Specification of digital dust indicator

Digital Dust Indicator	SIBATA, LD-3K2
Dust concentration conversion factor	0.002mg/m^3/cpm
Measurement accuracy	±10% of constituent particle
Measurement sensitivity	1CPM = 0.001mg/m^3
Measurement range	0.001~10.00mg/m^3

3-3-2 Dust concentration measuring system using ANN techniques

Dust concentration can be measured by use of artificial neural network (ANN)[4] techniques. Figure 3-4 presents a dust concentration measuring system that utilises an ANN. This process mainly consists of flash photographs as input, and these photographs are used for estimating the average and variance of feature values. These values are considered as input parameters for the input layer in the ANN. The detailed processes are described below.

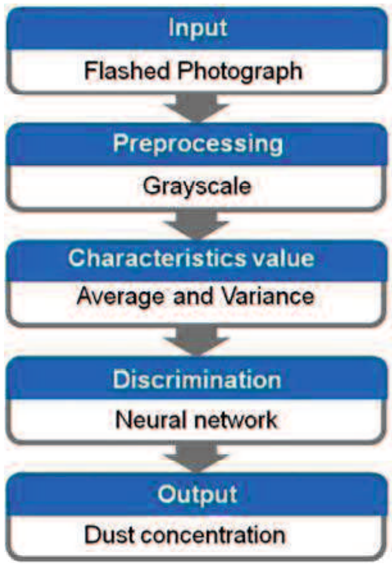


Figure 3-4 Dust concentration measuring system using ANN techniques

<u>Prepossessing</u>

In the photographs taken by the smartphone, each pixel is represented by three values: Red, r_{ij}; Green, g_{ij}; and Blue, b_{ij} (RGB). To simplify further processing, each RGB value is transformed into greyscale and scaled from 0 to 255 (256 levels in total) by application of Equation (3-1).[5] The resulting values comprise a matrix a_{ij} with n rows and m columns, where n and m represent the matrix size. Thus,

$$a_{ij} = 0.2989 \times r_{ij} + 0.5870 \times g_{ij} + 0.1140 \times b_{ij} \tag{3-1}$$

<u>Feature extraction</u>

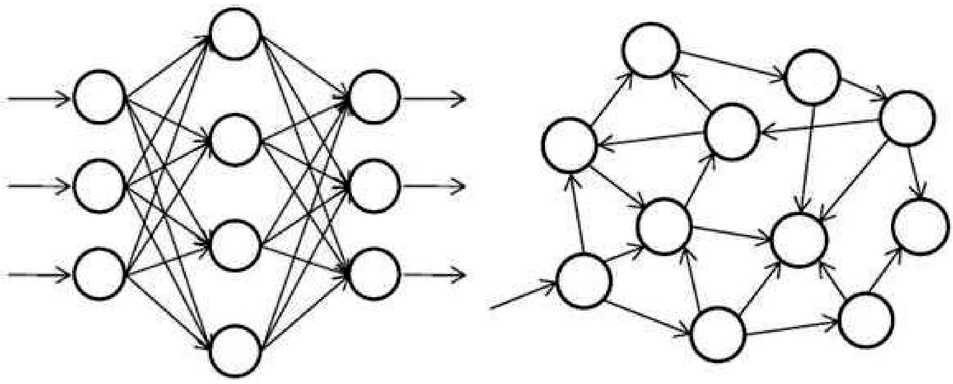
In the dust monitoring system (DMS) process, the average and variance of luminance values are calculated by Equations (3-2) and (3-3), respectively:

$$\overline{a} = \frac{1}{n \times m} \sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} \tag{3-2}$$

$$\overline{\sigma^2} = \frac{1}{n \times m} \sum_{i=1}^{n} \sum_{j=1}^{m} (\overline{a} - a_{ij})^2 \tag{3-3}$$

Artificial Neural Network

The relation between dust concentration and scattering light is complicated because of the variability of the amount of scattering light captured by the camera. Therefore, an ANN was adopted in this study to measure the dust concentration. An ANN is a computational system inspired by the structure, processing method, and learning ability of a biological brain. Such systems are used to address problems that are intractable or cumbersome with traditional methods. ANNs have two primary features: machine learning and pattern recognition. They can learn from the data and deal with unseen data based on experience (generalisation).[6] The details of ANNs are described below.



(a) Multilayer perceptron (b) Interconnecting network

Figure 3-5 ANN model

(1) Multilayer perceptron

An ANN consists of a number of interconnected processing units, commonly referred to as neurons or neurodes. Each of these neurodes receives input signals from other neurodes to which it is connected, and each of these connections has a numerical weight associated with it. ANNs have two main types of models: multilayer perceptron and interconnecting network (See Figure 3-5).

A multilayer perceptron is composed of multiple layers that are connected to each other. Its leaning function enables it to place input data into appropriate output. However, it was proved to be limited by the fixed increment rule, which is the principle that the leaning function cannot 'learn' all cases,[7] and the use of the multilayer perceptron has decreased. It is still used in areas related to brain science, such as biology, and a supervised learning system known as back propagation was devised.[8] Nowadays, it is used in the fields of economics, speech recognition, and image recognition.[9]

In this study, a dust measuring system utilising a multilayer, perceptron-type ANN with a back-propagation learning algorithm was considered. The principle of the system and back propagation are explained below. Figure 3-6 illustrates the concept of neuron movement.

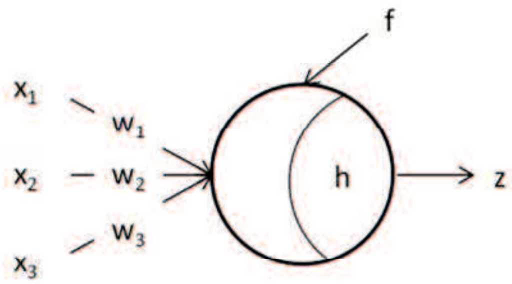


Figure 3-6 Unit model

Equation (3-4) shows that the neuron input is equal to the summation of input data x_i times the interpreted weight w_i minus a threshold value (h):

$$z = f\left(\sum_{i-1}^{n} w_i x_i - h\right) \tag{3-4}$$

The function value is the output, which is 0 or 1. For the post processing, the dust concentration is 0.0 mg/m^3 when the output value is 0 and 10.0 mg/m^3 for an output value of 1.

(2) Back-propagation algorithm

The ANN is composed of the expansion of these neuron movement concepts, and the multilayer perceptron is formed in an input and output layer plus intermediate layers called hidden layers (Figure 3-7). In the multilayer perceptron, the input pattern is weighted and transformed by certain rules into the output result. Because it creates only particular results, some adjustment methods are used to produce the desired output. Back propagation, which is the one of the representative methods, is a supervisory signal method. Through the learning signal, which can be obtained by the discrepancy between obtained and desired output combined with modification by weight and threshold value, it can deliver a satisfactory output value.

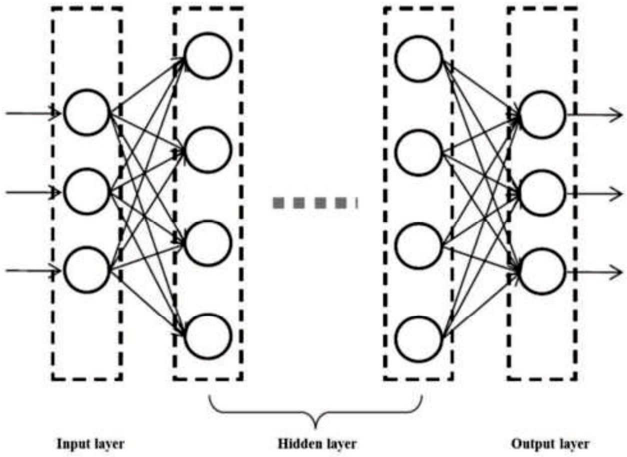


Figure 3-7 Multilayer perception

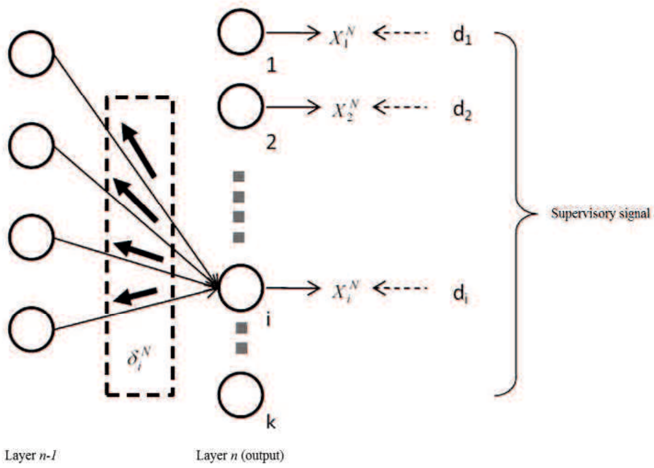


Figure 3-8 Supervisory signal and learning signal

As shown in Figure 3-8, each output layer sends a different learning signal to the layer before. The learning signal from unit i in the output layer is expressed as Equation (3-5) by use of the output value and the supervisory signal:

$$\delta_i^N = (d - X_i^N) f'(u_i^N) \tag{3-5}$$

The learning signal δ_i^n from unit i in layer n to layer $n\text{-}1$ is obtained by the following Equation (3-6):

$$\delta_i^n = f'(u_i^n) \sum_k \delta_k^{n+1} W_{k,i}^{n+1,n} \tag{3-6}$$

Therefore, learning signals from layer $u+1$ to unit i in layer n are summed and multiplied by weight. By multiplying the differentiation of the network function, the learning signal is calculated. The change in weight is

$$\Delta W_{i,j}^{n,n-1}(t) = \eta\delta_i^n X_j^{n-1} + \alpha\Delta W_{i,j}^{n,n-1}(t-1) \tag{3-7}$$

$W_{i,j}^{n,n\ 1}(t)$ represents the change in weight between unit j in layer n-1 and unit i in layer n and $\Delta W_{i,j}^{n,n\ 1}(t-1)$ for the previous calculation. The value η is the learning rate and is related to the speed of convergence. However, this relation does not mean that a larger η makes the learning speed faster. The value α is a stability constant defined by the previous change in weight and has an effect on control of the vibration of convergence. Both η and α are given as positive real numbers. The weight is modified as shown below:

$$\Delta W_{i,j}^{n,n\ 1}(t+1) = W_{i,j}^{n,n\ 1}(t) + \Delta W_{i,j}^{n,n\ 1}(t) \tag{3-8}$$

As described above, each unit constantly receives a signal that is weighted by the corresponding threshold value from the unit output 1.0. Therefore, the changes in threshold values are obtained from Equation (3-9):

$$\Delta h_i^n(t) = \eta\delta_i^n + \alpha\Delta h_i^n(t-1) \tag{3-9}$$

with the learning signals from Equations (3-5) and (3-6) and from Equation (3-8).

Thus, the equation for the modification is

$$\Delta h_i^n(t+1) = h_i^n(t) + \Delta h_i^n(t) \tag{3-10}$$

By repeating these processes, the error becomes smaller. The method to find a local minimum of the sum of squares of the errors is called the steepest descent method.

Determination of the ANN structure

The multilayer perceptron obtained by the back-propagation method is selected for the ANN in the DMS-S. The details of the ANN structure and the parameters must be determined. However, an underestimated value causes inadequate learning, and the generalisation capability would be stopped by an overestimation.[10] Because there is no established design theory, these values need to be selected based on the situation.[11] In back propagation, the global minimum of the error function is explored by the steepest decent method. The steepest decent method is essentially designed to find the local minimum, and there is no guarantee for the global minimum.

More layer numbers and more unit numbers create more local minimum numbers. However, the global minimums become increasingly likely to fall into the local minimum of the error function as layer number increases. Generally, the pattern identification ability increases with increasing numbers of layers and units. If the local minimums are similar to the global minimum, it is not a big deal in terms of pattern identification. In actual calculations, these numbers are determined by trial and error.

(3) The unit number of input layer and output layer

In the case of pattern identification of words, figures, and images, the number of input layers is determined by the dimension number of the feature vector required for each unit. The pattern identification ability increases with increasing dimension number; however, such increases increase the possibility of falling into the local minimum. In the DMS-S, the unit number is defined as 2 because two different feature values are input from the flash photograph. The number of units in the output layer is set to 1, which is equal to the output pattern number.

(4) Interlayer number and interlayer unit number

An ANN that does not have an interlayer can only solve linearly separable problems in the hyperplane, the same as the simple perceptron. Pattern separation ability increases with the number of interlayers. Pattern classification in arbitrary feature vector space becomes available when 2 interlayers are used.[12] The learning convergence improves but there is less flexibility to infer data reversely.

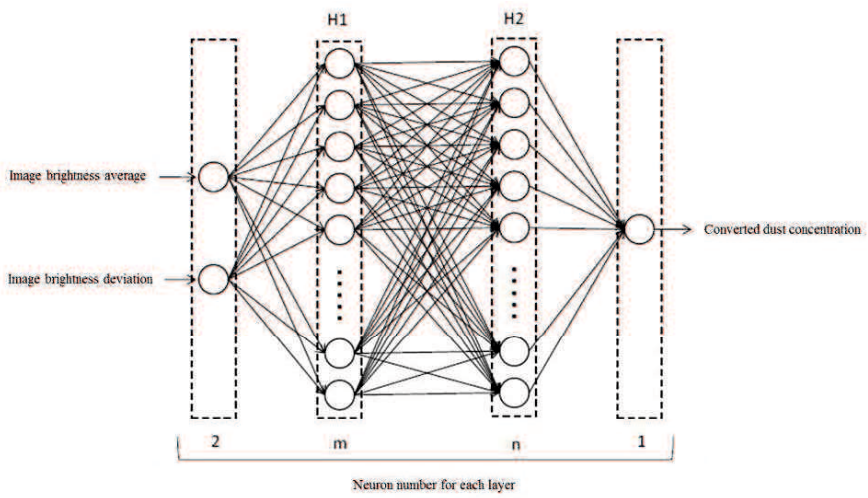


Figure 3-9 ANN model with 2 hidden layers

In the DMS-S, with 1 to 2 interlayers and 1 to 10 units in the interlayers, the optimised structure is considered. As shown in Figure 3-9, the interlayer is denoted as H1, H2 from the input layer side. When there are 2 interlayers, the unit numbers in H1 and H2 are considered the same because, in many cases, these numbers are the same and can be distinguished only by the pattern identification.[13]

Learning by ANN and the evaluation

Flash photographs connected with the digital dust indicator data are used as the measurement data. They are divided into learning data and test data. Test data are converted to the dust concentration by an ANN established by learning data and the correlation function of the converted data. The data from the digital indicator shown in Equation (3-11) are calculated to evaluate the DMS-S:

$$\rho = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})} \left(\frac{\sigma_x}{\sigma_y}\right), \qquad (3\text{-}11)$$

where $\bar{x}$ is the sample average of dust concentration by the DDI,

$\bar{y}$ is the sample average of the converted dust concentration,

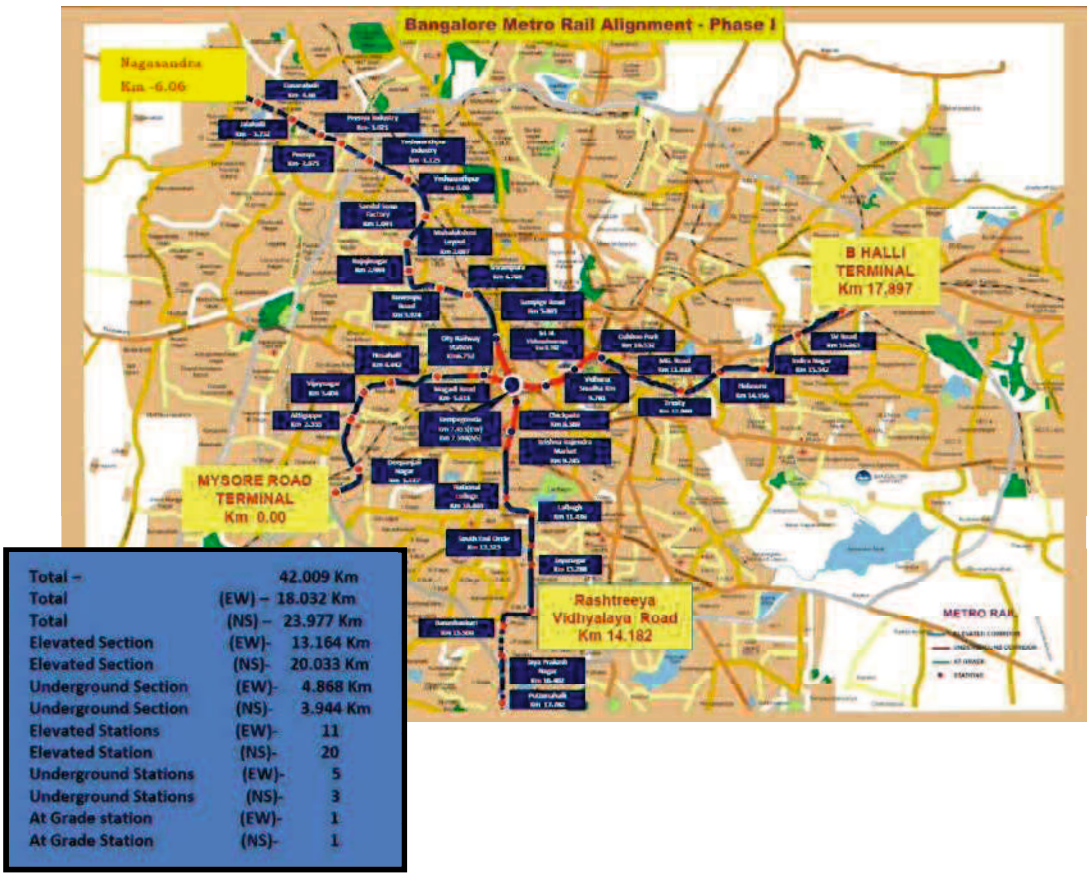
σ_x is the standard variation of dust concentration x by DDI, and

σ_y is the standard variation of the converted dust concentration y.

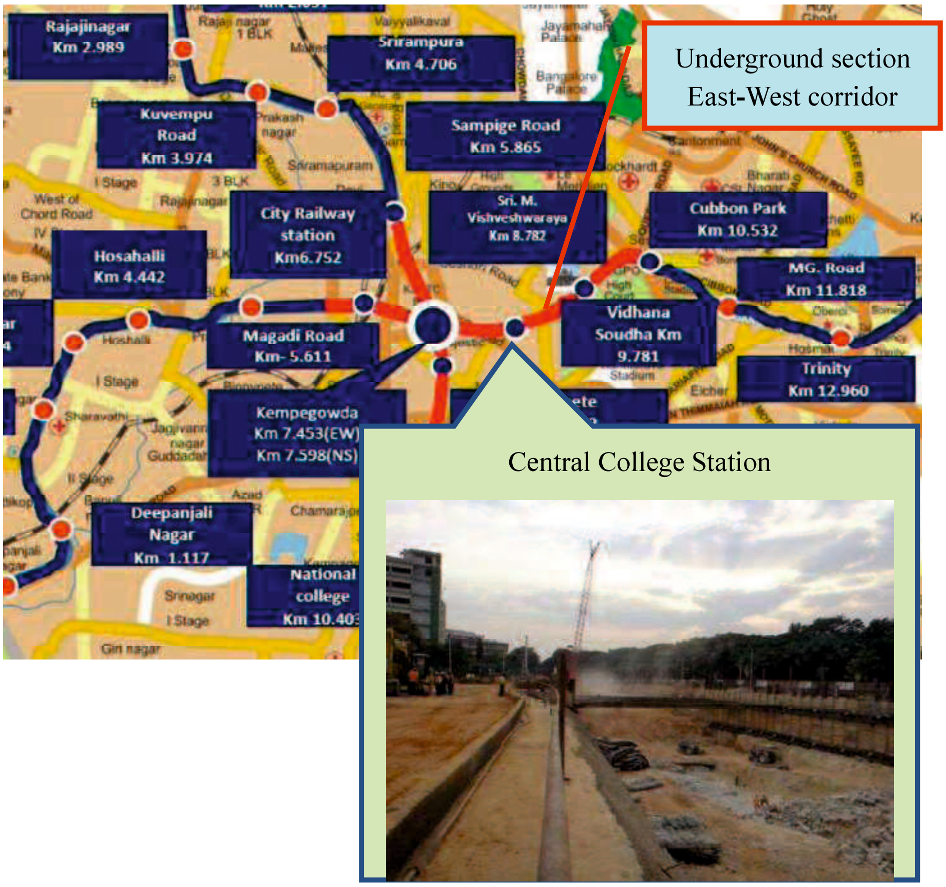
The correlation function ρ is expressed between 0 and 1.0, where higher values mean higher accuracy.

3-4 Case study of mobile phone-based dust measurement systems

Bangalore City is the capital city of Karnataka State in India and occupies an important position, not only in the state but also in the country. It is considered as one of the major industrial, commercial, and educational centres in southern India. Urbanisation in India is most rapid around the national capital and state headquarters. The city of Bangalore is no exception. The city has the dubious distinction of being the fastest growing metropolis in the country. Similarly, the vehicular population has been increasing tremendously, leading to traffic congestion and uncertainties in travel time for the commuter. To mitigate these problems, mass transit for Bangalore has been started under the responsibility of the Bangalore Metro Rail Corporation Ltd (BMRCL). Figure 3-10 shows the route map of the east–west corridor of the Bangalore Metro Rail Alignment Phase I. The red colour alignment shows the underground corridor and the blue alignment shows the elevated corridor.



(a) Overview



(b) Detail view and photo

Figure 3-10 Bangalore Metro map

3-4-1 Characteristics of the study area

For the present study, the Vishveshwaraya Station (Figure 3-10), also called the Central College Station (Km 8.78), of the east–west corridor of the Bangalore Metro Project Phase I has been considered. Figure 3-11 presents the station plan for construction of the Central College Station. In this study, four locations were identified to measure the dust concentration and are represented in Figure 3-11.

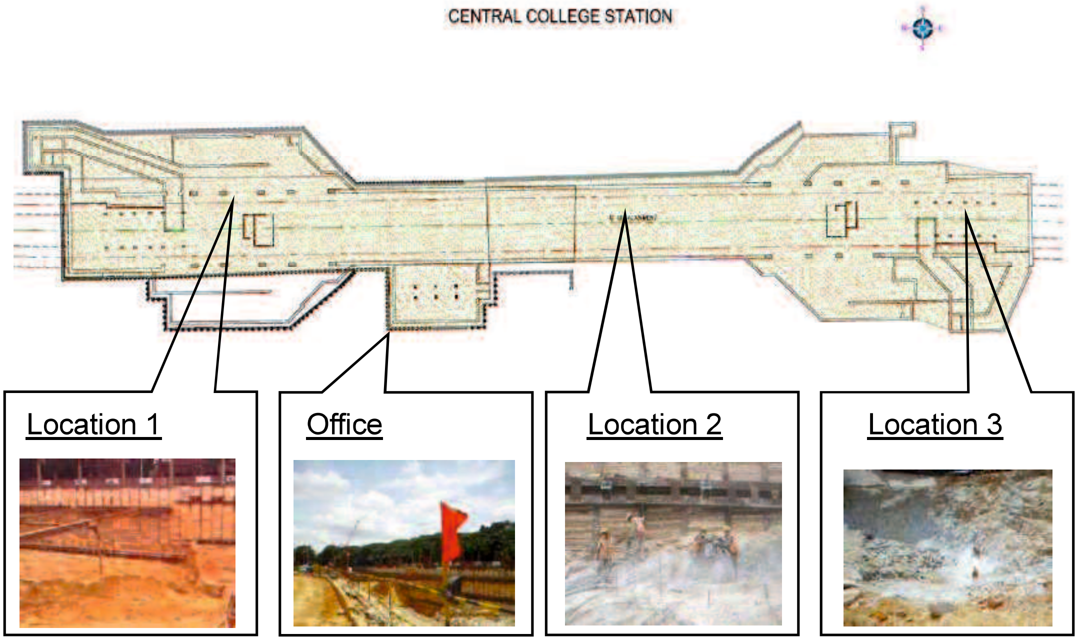


Figure 3-11 Dust monitoring site at the Central College Metro Station

3-4-2 Calibration and validation of the dust measuring system

A traditional digital dust measuring instrument, the SIBATA Digital Dust Indicator LD-3K2 model (Photo 3-3) dust monitor, was equipped with a laser that measures the relative concentration of respirable particles through the intensity of scattered light.[14] Before monitoring each day, background and span checks were conducted to remove filled air in the detector, to compare the measured value accuracy of the light scattering plate. The relative concentration of SPM with size less than 10 μm in diameter was measured every minute and expressed as count per minute (CPM). A dust measuring system developed from a mobile camera requires calibration before collection of real data. For this purpose, the photos taken in a dust box (Figure 3-12) were synchronised with the DDI, the calibration process was conducted for calibration and validation of DMS values, and correlation analysis was performed. This process is discussed in subsequent sections.

Photo 3-3 Dust concentration measurements by DDI

a) Calibration of the dust measuring system

Correlation analysis was carried out between dust concentration measured by mobile phone camera and dust measured by DDI to show the degree of correlation among values obtained by both these techniques. For this analysis, 108 samples were collected simultaneously by using both techniques. The sample collection of dust concentration data is spread over various time periods, such as morning, afternoon, and evening hours, at four different locations within the study area represented in Figure 3-11. The correlation between the dust concentration by mobile phone (mg/m^3) and dust concentration by DDI is presented in Figure 3-12. A highly positive correlation (R = 0.94) exists between the dust concentrations measured by the two techniques.

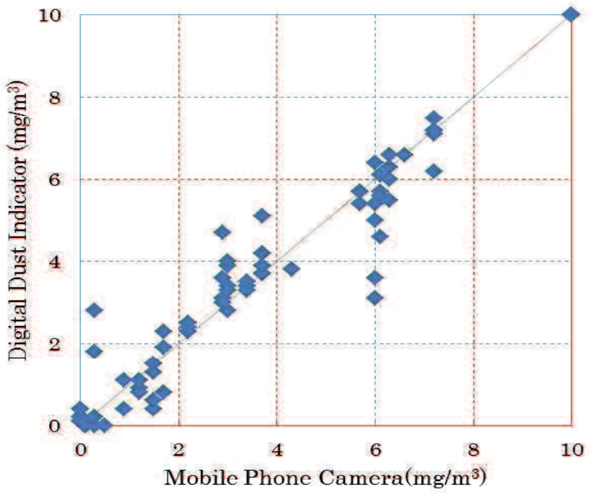


Figure 3-12 Correlation of dust values obtained by mobile phone camera and DDI

Further, regression analysis was carried out to understand the relation among the dust concentrations measured by these methods. The estimated regression model coefficients for the collected sample are presented in Table 3-4. The sign of the estimated coefficients of the variable is positive, which indicates that the dust concentration measured by mobile phone showed a positive contribution to the DDI value. Based on *t*-statistic values (greater than 1.95), there is a significant relation among these values. The estimated R^2 values were as high as 0.88, which indicates that the uncertainty explained by these values is very high (88%). Also, the observed F-value is high (799.284), and significance of the *P*-value is less than 0.005. This result emphasises that the dust concentration values observed by mobile phone camera are significant. Further, these values were validated on statistical grounds by using the standard *t*-test and F-test. These tests are discussed in the following section.

Table 3-4 Coefficients estimated by linear regression analysis

	Coefficients	Standard Error	t-State	P-value
Intercept	0.118	0.148	0.797	0.427
DMS (mg/m^3)	0.945	0.033	28.272	0.000

b) Validation of the dust measuring system

Further validation of dust concentration data obtained by the mobile camera method was validated against the DDI dust concentration values. Mainly, these values are statistically validated by considering the Student's *t*-test for significance of difference between the means of observed DDI values and DMS values. The F-test is also considered for validating the significant difference in variance of observed dust values obtained by both instruments. The method of estimation of these two statistical tests is discussed below.

The *t*-statistic value is estimated using Equation (3-12) to assess the statistical validity of the mean relationship between the dust measured by mobile phone (DMS) and DDI:

$$t = \frac{x_a - x_m}{\sqrt{\frac{s_a}{N_a} + \frac{s_m}{N_m}}} \tag{3-12}$$

where x_a and x_m, the mean values of dust concentration, are measured by mobile phone and DDI, s_a and s_m are the variances of DMS and DDI dust concentration measured values, and N_a and N_m are the sample sizes of DMS and DDI values. It can be observed from Table 3-4 that the *t*-value obtained by Equation (3-12) is less than the *t*-critical value for the 5% level of significance, which is obtained from the standard *t* table. This emphasises that the dust values measured by mobile phone have no significant difference from dust values measured by DDI.

Similarly, the F-test value has been estimated using Equation (3-13) to assess the statistical validity of variance between the dust measured by mobile phone and DDI:

$$F = \frac{s_a^2}{s_m^2} \tag{3-13}$$

where s_a^2 and s_m^2 are the standard deviations of observed and modelled PSR values, respectively. As observed in Table 3-5, F-values obtained by Equation (3-13) are less than the F-critical value for the 5% level of significance, which is obtained from the standard F-table. This observation suggests that the dust concentration values obtained by the mobile phone camera are statistically significant.

Table 3-5 Statistical summary of validation results of dust measuring

Dust values Measured by Mobile Phone		Dust Measured by DDI		Student t-test		F-test	
Average	Variance	Average	Variance	t-Value	t-Critical	F-Value	F-Critical
3.370	8.418	3.304	8.530	0.168	1.990	0.993	1.410

3-4-3 Data collection

After validation of the DMS, it was used in the present cut and cover Metro construction site. The developed DMS was difficult to use directly under the sunshine. To overcome this difficulty, a new dust monitoring chassis box was developed to measure the dust concentration, as shown in Photo 3-4. The dust monitoring box was kept open to unify the dust concentration before taking the measurement. Then, the box was closed and a flash photograph was taken in the dark box.

Photo 3-4 Dust monitoring system consisting of chassis box with mobile phone camera

For the present study, data were collected in the four locations represented in Figure 3-11. A total of 48 days of dust data were measured in the months of September, October, and November in 2011. Dust was measured in four different time periods of each day: 9:00 AM, 11:00 AM, 2:00 PM, and 5:00 PM. At each time, 4 dust samples were collected. The average concentration for each time period was estimated for each sample for each location, and the average of the concentrations was considered in the analysis and decision making for an action plan. The sample sizes collected for the various locations are presented in Table 3-6.

Table 3-6 Dust measuring location and sample size collected

Sl.No	Name of the Location	Sample Size
1	At Location 1	120
2	At Location 2	83
3	At Location 3	118
4	Near Site Office	124
	Total Sample	445

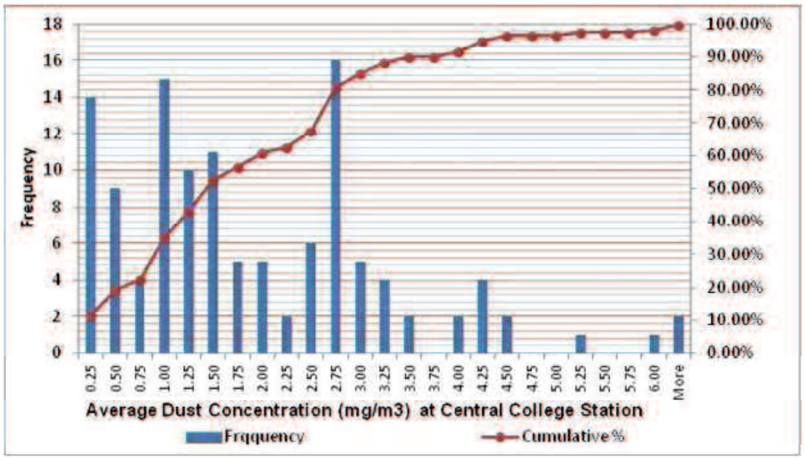
3-4-4 Results and discussion

The dust concentration data measured at all three locations were analysed and a summary of statistical parameters (such as mean, median, kurtosis, and skewness) for all locations were estimated and are presented in Table 3-7. This statistical information regarding the dust concentration is very useful for showing the central tendency and variability of the dust concentration at the measured locations of the study area during working hours. The table shows that the mean dust concentration at Location 3 is marginally higher than that at the other locations. Similarly, the standard deviation for this section is higher, with a value of 1.78 mg/m^3. The kurtosis value provides a measure of the ‘peakedness of dust concentration. Location 1 has a higher kurtosis value and indicates high peak values and less variability than at other locations. The particle size distribution of Location 3 is a little wider than the dust influence at Locations 1 and 2. Dust collected over the entire sampling interval was low; however, when the dust concentration included that for the interim drilling time, dust exposure increased. Further, to discuss this scenario in detail, additional and repeated measurements of dust concentrations is necessary. Based on the observations, it is recommended that the workers should wear masks with watering filters during drilling at the locations.

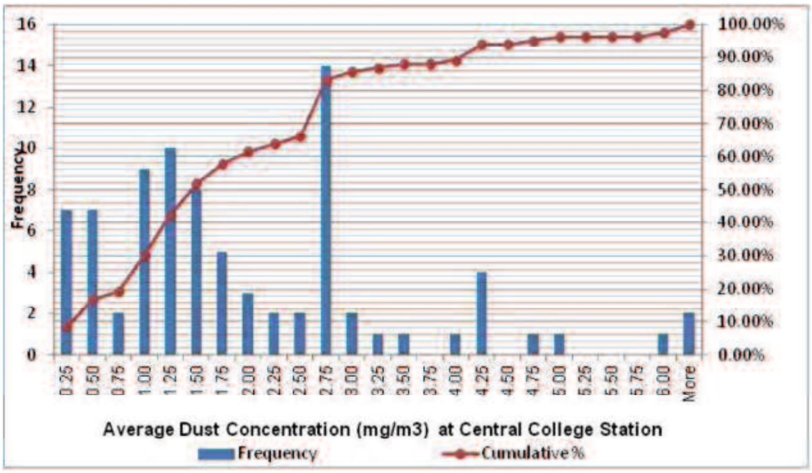
Table 3-7 Statistical summary of the dust concentration measures at the study area

Statistical Parameter	*Location 1*	*Location 2*	*Location 3*	*Combined*
Mean	1.84	1.91	2.05	1.97
Median	1.33	1.36	1.56	1.36
Standard Deviation	1.63	1.62	1.78	1.75
Kutosis	7.83	7.08	5.55	5.60
Skewness	2.14	2.09	2.03	2.01
90th % Dust Concentration	3.40	4.0	4.20	4.20

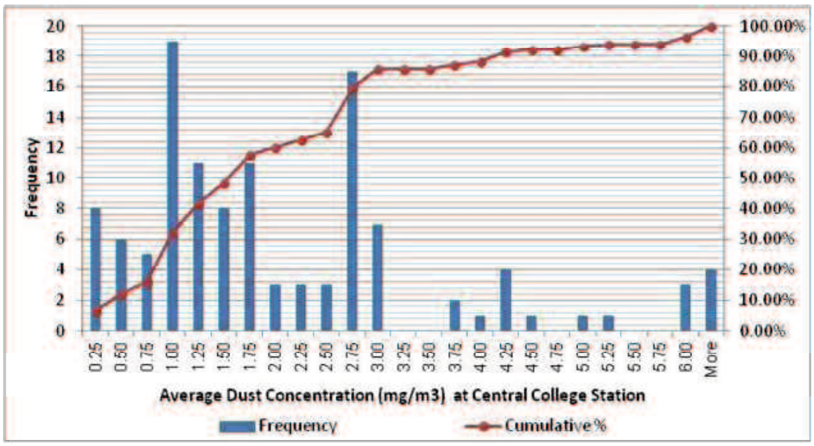
The probability distribution of the particle size of the dust concentrations at individual locations and the combined data are presented in Figure 3-13 and Figure 3-14. The figures show that all the distributions are skewed to the right. The cumulative distribution shows that the median value (at 50%) is almost the same in all the locations and is approximately 1.4 mg/m^3, except at Location 3, where it is approximately 1.60 mg/m^3. The 90th percentile of dust concentration levels are crossed at a lower safe limit of 3.0 mg/m^3. This observation can be simply explained by the fact that, out of 20 measured samples, two samples of dust concentration levels exceed the lower concentration level at all three locations. Therefore, the observed results strongly suggest that the workers should at least use simple dust masks while working at any location.



(a) Distribution at Location 1

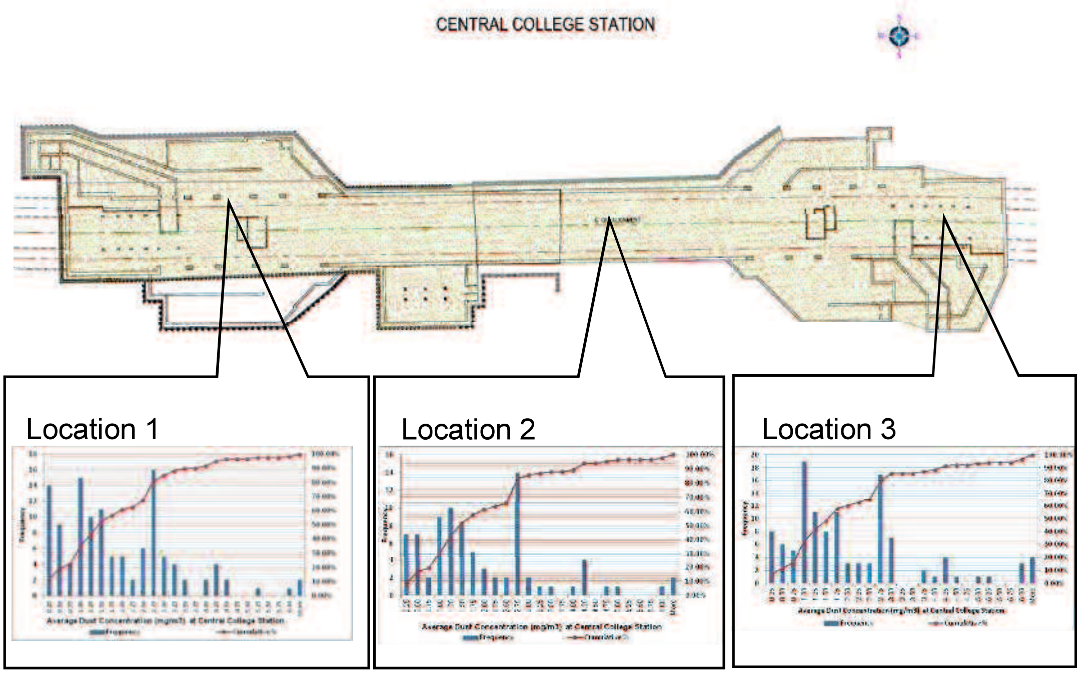


(b) Distribution at Location 2



(c) Distribution at Location 3

Figure 3-13 Average particle size distribution of samples collected in each location at Central College Station



(d) Location map with monitoring results

Figure 3-13 Average particle size distribution of samples collected in each location at Central College Station

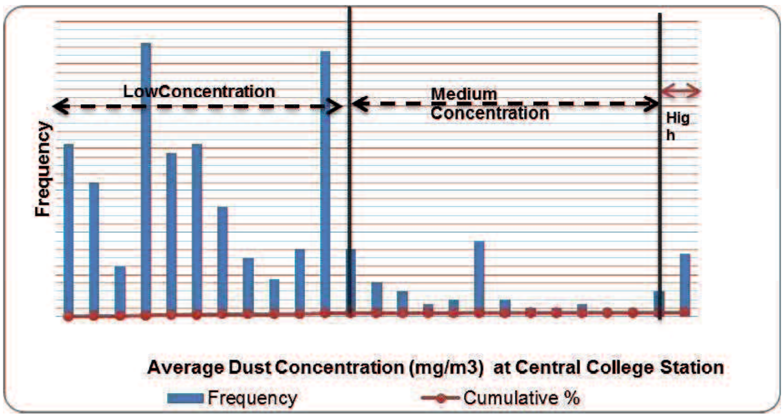


Figure 3-14 Combined average particle size distribution of samples collected at Location 1, Location 2, and Location 3

3-5 Environmental assessment and dust monitoring allocation

The BMRCL's Safety Health Environment (SHE) manual[15] stipulates that the contractor shall take all necessary precautions to minimise fugitive dust emissions from operations involving excavation, grading, and cleaning of land and disposal of waste. The contractor already submitted and obtained approval for an air quality monitoring programme at the beginning of the project. According to the manual, the summary of the contractor's monitoring programme for air is shown in Table 3-8.

Table 3-8 Summary of contractor's monitoring programme for air

Parameter	Air
Sampling	RSPM, SPM 24-ours of the day CO:12hrs from 8:00 to 20:00hrs
Frequency at Each location	Two 24-hour Samples every fifteen days at uniform intervals
Location	To be determined by the Contractor based on air sensitive receptors
Number of Locations	2 locations
Duration of Monitoring by Contractor	During Civil Construction
Additional Requirements	Ad hoc monitoring as required

Based on the above summary of the contractor's monitoring programme for air, the dust monitoring team made a specific environmental assessment with allocation for a DMS for the Central College Metro Station construction site, as shown in Table 3-9.

Table 3-9 Specific environmental assessment with allocation for a dust monitoring system for the Central College Metro Station construction site

Parameter	Dust Monitoring System
Sampling	Floating Dust
Frequency at Each location	Four times. 9:00, 11:00, 14:00 and 17:00 in each location
Location	Soil excavation place, Rock excavation place and near the office
Number of Locations	4 locations
Duation of Monitoring by Contractor	During Civil Construction
Additional Requirements	Ad hoc monitoring as required

3-5-1 Contractor's environmental management system

According to the contract requirement, the contractor shall establish an environmental plan, including dust monitoring, after the awarding of the contract. The objectives of the dust monitoring can be summarised as follows.

- Measure the dust concentration at the site.
- Inform the workers on the site about the concentration.
- Take action, depending on the dust concentration.
- Provide dust monitoring system practice to carry out normal operations at the work site.
- Create awareness that dust management is prevention of workers' future health problems.
- Strive to continuously improve dust management skills.

(1) Environmental work practices/procedures

All work items at the site shall be performed with proper working procedures in terms of SEH. The objective of the safe work practices/procedures is to eliminate, or reduce to a minimum, the risk of death or injury to persons and damage to properties and assets during the execution of the work. Major items of safe work practices/procedures are listed below.

1. Permit to work
2. Excavation works
3. Transportation
4. Working at height
5. Electrical work
6. Crane operators
7. Welding and cutting
8. Fire prevention
9. Handling of chemicals
10. Noise control
11. Dust control
12. Waste management

(2) Site environmental performance

Despite the above mention of dust control, there is no mention of monitoring and the JICA team did not find any indication of inspections for dust monitoring or actions for dust control. Environmental dust monitoring should be conducted to protect workers' health and, in high-dust-concentration situations, actions for dust should be immediately taken. The major items of site environmental dust performance are listed below.

1. Daily dust monitoring by SHE engineer
2. Education on actions regarding the dust concentration
3. Environmental dust induction talk for newcomers
4. The accuracy check of DMS by JICA team
5. Site inspection by SHE engineer

(3) Environmental awareness training and programmes

The objective of environmental training and programmes is to equip personnel with the knowledge, skill, and attitude that will enable them to perform their duties of dust monitoring. Major activities of environmental dust awareness training and programmes are listed below.

1. Training for site SHE engineers
2. Training on DMD
3. Wearing dust mask training programme
4. Dust monitoring drill
5. Lifting equipment and tool tackles inspection and awareness
6. Environmental dust awareness programme

3-5-2 Environmental management activities with dust monitoring

The environmental management activities with the DMS at the Central College Metro Station are evaluated and selected in terms of the following aspects.

- Inclusion of dust monitoring effectively as part of environmental activity
- Improvement of environmental awareness, both for contractors and for workers, to build an advanced working environment
- Improvement of environmental control techniques through the execution of dust monitoring

Based on the above evaluation items, the following activities are selected for the execution of environmental management activities with the DMS at the Central College Metro Station:

1. Environmental DMS induction talks to BMRC, contractor, and worker
2. Daily dust monitoring and inspection with DMS
3. Environmental training by medical doctor regarding the risk of dust

In the method statement for the excavation at the Central College Metro Station, the above activities were specified with detailed required procedures.

3-5-3 Execution of safety management activities with dust monitoring

(1) Environmental DMS induction talks to the contractor

a) Approach

Dust monitoring and its environmental activities are new to the contractor. The presentation and discussion on environmental DMS induction were conducted for the BMRC and the contractor's engineers to provide an understanding of the DMS. (Photo 3-5). The following items were explained and discussed.

- Target of the DMS
- The risk of dust
- Contents of the DMS
- Site arrangement of dust monitoring
- Trigger values of dust monitoring
- Action plan for colour changes

Photo 3-5 Presentation of environmental DMS induction

An environmental DMS induction talk to all workers at the site was given by the JICA team using the sign boards shown in Figure 3-15. The explanation was in the Hindi language (Photo 3-6).

- The risk of dust
- The colours show the dust concentration at each place
- 'Yellow colour' means 'wear a simple dust mask'
- 'Red colour' means 'wear a filter dust mask'
- Drilling workers face high-dust-concentration situations, so they should always wear an electric fan dust mask

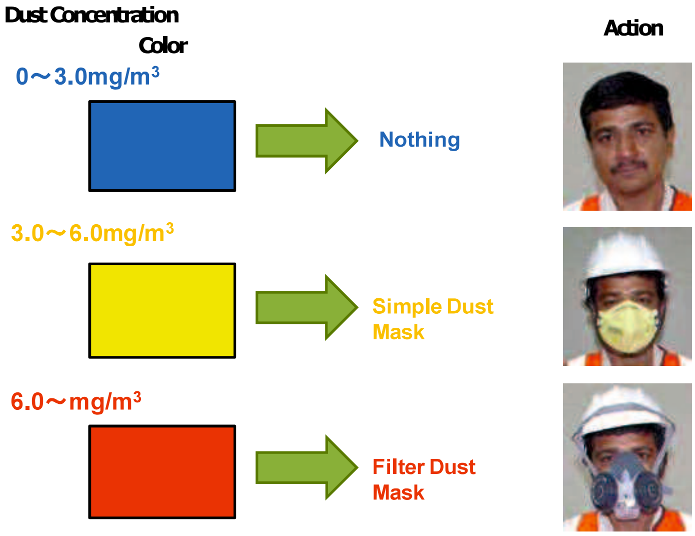


Figure 3-13 Actual action plan

Photo 3-6 Environmental DMS induction talk to workers

b) Results

Usually, no information is given to site workers about site monitoring issues, the role of the report for colour changes, or detailed action for dust. Therefore, these activities had considerable effects in raising environmental consciousness and improvement of dust monitoring techniques for the BMRCL, the contractor, and the workers.

(2) Daily dust monitoring and inspection with DMS

a) Approach

Daily dust monitoring and inspection with the DMS was conducted with the BMRC, the JICA team, and the contractor during the excavation stage at the Central College Metro Station (Photos 3-7 and 3-8).

Photo 3-7 Daily dust concentration check sheet at the Central College Metro Station

Photo 3-8 Daily site walk with the BMRC, the contractor, and the JICA team

b) Results

Through these activities, the following effects were observed.

- Improvement of environmental awareness was achieved
- Technical discussion and advice were given
- Environmental team spirit between the BMRC and the contractor was developed

(3) Environmental training by medical doctor regarding the risk of dust

a) Approach

The contractor and the workers did not recognise the risk of dust. To enhance the awareness of dust risk, a medical doctor was invited by the dust monitoring team to provide environmental training (Photo 3-9).

Photo 3-9 Environmental training with a medical doctor at the Central College Metro Station

b) Results

All drilling workers (4 people) began to wear electric fan masks everyday. The following observations were made during the evacuation drilling, as show in Photo 3-10.

- Workers understood the risk of dust and the meaning of dust monitoring
- The medical doctor's talk was very effective in raising environmental awareness about dust and improving environmental attitudes

Before training

After training

Photo 3-10 The workers' condition before training and after training

3-5-4 Environmental information for the site

A website was created at http://cistup.iisc.ernet.in/~osvbng/, where the data from the dust monitoring programme have been uploaded and are available with a password at http://cistup.iisc.ernet.in/~osvbng/osv.html. Dust monitoring has been done using two systems.

A backup of all the dust monitoring data from …. to Jan 2012 has been uploaded at the Center for Infrastructure, Sustainable Transportation and Urban Planning (CiSTUP) website in the Indian Institute of Science (IISc), Bangalore, India. This website was continuously accessed on a daily basis by all the stakeholders: IISc, BMRCL, Oriental Consultants, Kobe University, and Yamaguchi University. Details of the project, the site map, and the location of dust monitoring have been uploaded to the site, along with analysed data about the dust density. Further, photographs of the site as the excavation progressed (every day) have also been uploaded (Figure 3-16).

Figure 3-14 Display on PC screen (dust monitoring)

3-6 Question survey regarding dust monitoring

3-6-1 Objective and scope of the survey study

(1) Objective of the survey study

The main objective in this chapter is to evaluate the use of dust monitoring methods at construction sites of the Bangalore Metro Rail Construction (BMRC) by considering the following evaluating criteria.

- Safety awareness and consciousness among various stakeholders during construction
- Recognition of dust monitoring and safety issues
- Effectiveness of dust monitoring techniques
- Contribution of dust monitoring in environmental activities/management
- Improvement of health consciousness through dust monitoring techniques and activities

(2) Scope of the survey study

Data collection and coding

The data were collected in the designated formats for various groups. During the surveys, discussions were also held with various officials and site engineers of the client (BMRC) and the General Consultants team. The data formats have been designed separately for dust monitoring for three groups, namely site engineers, workers, and residents/road users. The key parameters considered in the opinion survey on dust monitoring are briefly discussed in the following sections. The schedule of the opinion survey for dust monitoring is presented in Table 3-10.

Table 3-10 Schedule of opinion survey for dust monitoring

Sl.No	Name of The Opinion Survey	Date of Survey	Location of Survey	Sample Size
1	Workers - Before Training	22/8/2011	Central College Station	43
3	Workers - After Training	5/1/2012	Central College Station	46
5	Workers - No – Dust Monitoring	5/1/2012	Vidhan Soudha	31
7	Engineers/Officers - Before Training	22/8/2011	Central College Station	11
8	Engineers/Officers - After Training	6/9/2011	Central College Station	14
10	Engineers/Officers - No - OSV Situation	6/1/2012	Vidhan Soudha	8
11	Engineers/Officers – at Site Offices	6/1/2012	UG 2 Office	8
12	Road Users	6/1/2012	In front of Central College	29

(3) Opinion survey on dust monitoring method

Site engineers and officers

The survey team gave demonstrations and trained the site engineers of the contractor, officials of General Consultants (GC), and other BMRC officials associated with the Central College Metro Station. A separate format has been devised (Set A) for this group and is presented in Appendix 3. The information collected includes personal details, working experience, dust monitor and control experience, and dust monitoring experience by the mobile phone camera method.

Site workers

An opinion survey on dust monitoring for day-shift worker groups was carried out at the Central College Metro Station. Parameters such as personal details, working experience, dust awareness, and dust monitoring experience by mobile phone camera were collected. The data collection for this group (Set B) has been used and is given in Appendix 3. Before conducting the survey, the team organised dust awareness programmes for site workers and engineers at this site. For a view of the confirmation and countermeasures appropriate to all dust concentrations for workers during construction, the dust concentrations were reported on display boards provided at the study area. The action plan display boards can be easily distinguished and are useful to site personnel in applying appropriate countermeasures. By changing the panel colour according to the results of measuring, workers can easily know the level of dust concentration and implement the countermeasures.

Road users

Road users in front of the Central College Metro Station were also surveyed. The survey team organised a brief demo for the road users by showing the pamphlets on dust-related safety awareness. After that, an opinion survey for this group was conducted as per the designed parameters. The performa that was used for this group is provided in Appendix 3 (Set C). This format has been specially designed for this group and also for the randomly selected public, who move closely around the construction site near the Central College Metro Station; this group includes students and faculty of Central College, lawyers of the Bangalore judicial court, and the general public (road users).

Workers at the Vidhan Soudha Station

To make a comparative evaluation of health awareness with and without dust monitoring, sufficient samples of workers and site engineers were taken and data were collected at the

Vidhan Soudha Metro Station. The same formats have been used for this purpose. The knowledge on dust was already provided to the site engineers at the Vidhan Soudha Metro site office. For this group, Set C (Appendix 3), limited information has been used for data collection.

Data coding for dust monitoring

The data collected through the opinion survey for dust monitoring from the three groups were coded and transferred appropriately to the Microsoft Excel software to carry out detailed category analyses. The collected data for various groups are presented in annexure 14 (Site Engineers/Officers at Central College Station), annexure 15 (Workers at Central College Station), annexure 16 (Workers at Vidhan Soudha Station), annexure 17 (Road Users in front of Central College Station), and annexure 18 (Participants of training at IISc Bangalore) of the JICA SAPI final report.

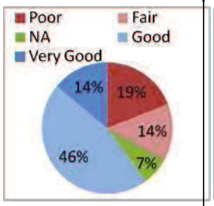
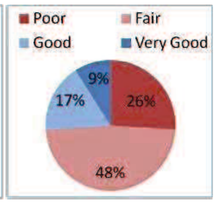
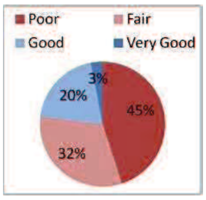
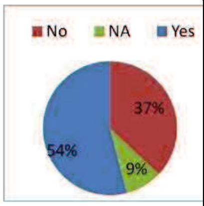
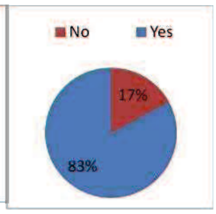
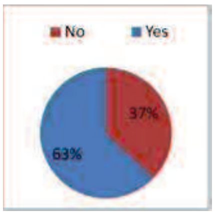
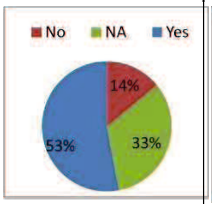
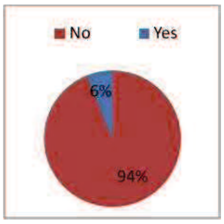
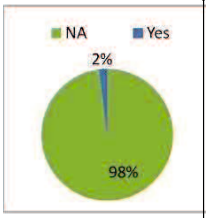
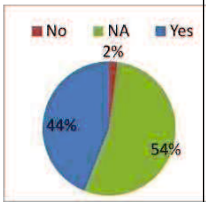
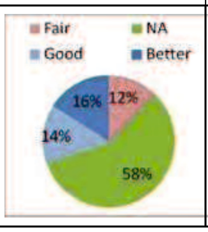
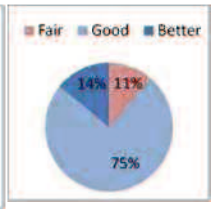
3-6-2 Data anlysis for dust monitoring

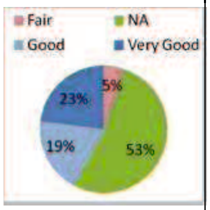
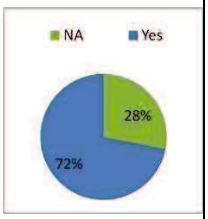
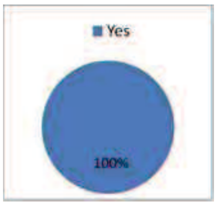
Data analysis has been carried out for dust monitoring on various issues, such as understanding the level safety knowledge and the safety and health experience of workers, engineers, and road users. Some important parameters for various groups are considered and analysed. The results of the analysis are discussed groupwise in the following subsections. The analysis has been carried out in two ways: (1) grading the opinion on a four/three grade-point scale and (2) categorisation of the choice of the opinion expressed (pie chart).

(1) Site workers

Randomly, 46 site workers at the Central College Metro Station (CCL) before and after training were interviewed, and 31 site workers at the Vidhan Soudha Metro Station (VS) (without monitoring method) have been interviewed. Table 3-11 shows that the level of dust consciousness was good before training at the Central College Metro Station (CCL), but consciousness has become very good after training. The percentage of dust-related safety awareness among workers at the Central College Metro Station (CCL) has increased from 54% to 83%, whereas awareness among workers at the Vidhan Soudha Metro Station (VS) is at 63%. After training, workers at the Central College Metro Station (CCL) are fully aware of the colour code of the dust monitoring techniques, fully aware of health consciousness, and fully informed for future Metro construction projects. The workers at the Vidhan Soudha Metro Station (VS) also fully agreed that this monitoring method changed their attitude and health consciousness after learning from the pamphlets on dust monitoring. All the workers at the Central College Metro Station (CCL) understand the purpose of the monitoring method after training. In the case of the Vidhan Soudha Metro Station (VS), approximately 94% of the workers understand the purpose of the dust monitoring method at construction sites.

Table 3-11 Opinion of site workers about dust monitoring

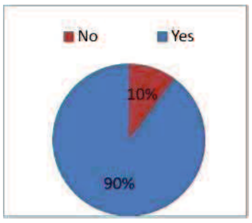
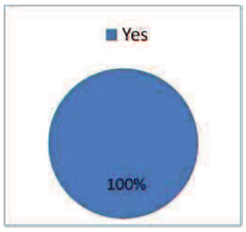
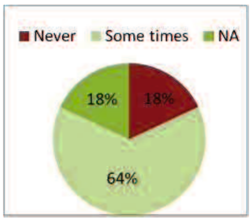
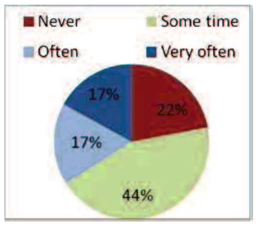
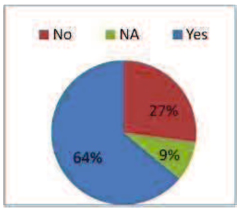
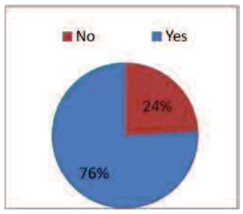
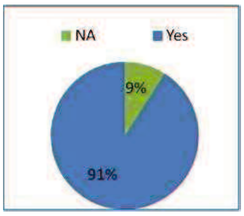
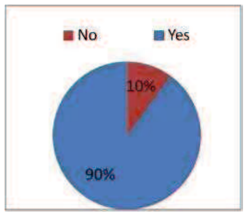
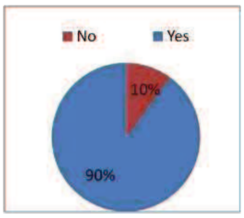
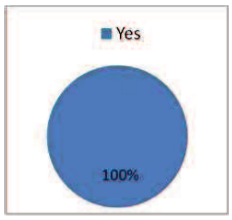
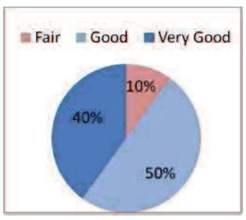
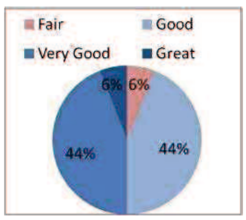
<table>
<tr><th>Sl.No</th><th>Parameters of Opinion Survey</th><th>Workers Before Training at CCL (Samples Size 41)</th><th>Workers After Training at CCL (Sample Size 46)</th><th>Workers No Dust Monitoring at VS (Sample Size 31)</th></tr>
<tr><td>1</td><td>How much conscious on dust do you have during working at site?</td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>Do you think current dust related safety measures are enough?
(Blue: Yes; Red: No; Green: Can’ Say)</td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>Do you understand the purpose of Dust Monitoring method?
(Blue: Yes Red: No)</td><td></td><td></td><td></td></tr>
<tr><td>4</td><td>Have you understand the meaning of dust colour panel colour provided at the work?
(Blue: Yes Red: No)</td><td></td><td></td><td></td></tr>
<tr><td>5</td><td>Do you agree this dust monitoring method will change your attitude and health conscious?</td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>If agree, how much rate of improvement health conscious by introducing Dust Monitoring Method?</td><td></td><td></td><td></td></tr>
</table>

Sl.No	Parameters of Opinion Survey	Workers Before Training at CCL (Samples Size 41)	Workers After Training at CCL (Sample Size 46)	Workers No Dust Monitoring at VS (Sample Size 31)
7	How would you rate use of dust monitoring method in construction monitoring?			
8	Will you recommend dust monitoring method for other /Future Metro constructions?			

(2) Site engineers and officers

A total of 31 officials comprising site engineers of the contractor (CEC-SOMA-CICI JV) and officers of the BMRC have been interviewed before and after evacuation training. Their experiences with dust monitoring and their opinions on the present dust monitoring are presented in Table 3-12. Results from Table 3-12 show that most of the engineers/officials have awareness of dust effects. Also, this group has attended dust monitoring and control programmes. Almost all the engineers understood the purpose of the mobile phone camera-based dust monitoring programme. Approximately 90% of the engineers rated this method as good for construction monitoring, and 90% of the engineers before training recommended this method for future Metro monitoring. After training, all the engineers recommended this method for future Metro construction.

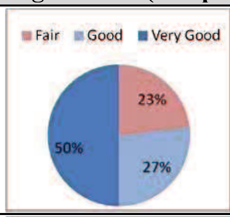
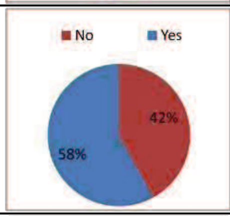
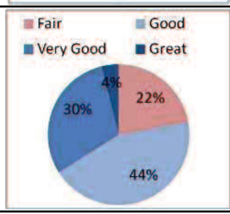
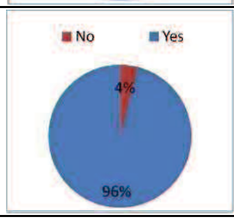
Table 3-12 Opinions of site engineers/officers about dust monitoring

Sl. No	Parameters of Opinion Survey	Before Training (Sample Size 11)	After Training (Sample Size 20)
1	Do you aware about the effect of dust?		
2	How often have you attended dust Monitoring and Control programming?		
3	Do you think current dust control measures are enough?		
4	Do you understand the purpose of Dust Monitoring method?		
5	Will you recommend dust monitoring method for other /Future Metro constructions?		
6	How would you rate use of dust monitoring method in construction monitoring?		

(3) Road users

The safety knowledge and opinions of 29 road users regarding the dust control method have been analysed randomly in front of the Central College Metro Station and are presented in Table 3-13. The table shows that 50% of the road users were conscious about their health and 50% of the subjects were aware of the dust monitoring at the BMRC construction site. The survey team explained through pamphlets about the mobile phone dust monitoring method, and 80% of the road users said the survey team significantly increased their health consciousness by introducing the dust monitoring method to them. Seventy-five percent of the responders rated the use of the dust monitoring method as good in construction monitoring, and most of this group recommend the dust monitoring method for other/future Metro construction.

Table 3-13 Opinion of road users about dust monitoring

Sl.No	Parameters of Opinion Survey	Road Users at Central College Station (Sample 29)
1	How much health consciousness do you have?	
2	Are you aware of the dust monitoring at the BMRC construction site?	
3	How much rate of improvement health conscious by introducing Dust Monitoring Method?	
4	How would you rate use of dust monitoring method in construction monitoring?	
5	Will you recommend dust monitoring method for other /Future Metro constructions?	

3-7 Observation and conclusions for improvement of dust monitoring systems

3-7-1 Observations for improvement of dust monitoring methods

The following recommendations were determined based on the collected samples to further improve dust monitoring methods.

Dust monitoring method

Dust monitoring by the mobile phone camera method is dynamic and an ideal alternative to traditional methods, such as the DDI.

- *Awareness Programmes:* Further, frequent awareness programmes incorporating cautions for health related to the impact of dust are required to enhance awareness of workers. These programmes will motivate the workers to use proper masks during work at Metro construction sites.
- *Real-Time Dust Data Collection:* Real-time dust data collection and information will be very useful in encouraging site workers and engineers to take proper precautions during work.
- *Dashboard Display:* Online measurements and information through electronic display messages during construction are very useful in alerting engineers as well as workers to take proper protective measures immediately.
- *Meteorological Information:* Weather information, in particular seasonal and daily wind patterns, will give additional information to the site engineers and workers regarding the need to take additional precautions during blasting or drilling.
- *Development of Guideline Dust Levels:* Development of proper guidelines and a set of procedures for these innovative monitoring techniques in Metro construction sites are essential. They will be useful in establishing a baseline for dust levels at Metro construction sites in India

3-7-2 Concluding remarks and recommendations

The following key findings of the study have been discussed, and recommendations have been proposed for further improvement of dust monitoring methods.

3-7-3 Recommendations

- Dust monitoring by the mobile phone camera method is dynamic and an ideal alternative to traditional methods, such as the DDI.
- Further, this method compares well with the standard DDIA.
- Online measurements and information transmitted through electronic display messages during construction are very useful in alerting engineers as well as workers to take proper protective measures immediately.
- Frequent training for workers is required to help them understand the impact of dust on health. This training will change attitudes towards the use of proper masks during blasting and drilling.

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Chapter 4
DUST MONITORING SYSTEM BY IP CAMERA BASED ON VIDEO PROCESSING

4-1 Introduction

At tunnel construction sites, dust emitted from construction has been a serious problem for health and the environment. Since the impairment of lung function by dust pollution became an un-ignorable issue after the 1980s in Japan, the use of powered air-purifying respirators and regular dust measurements by digital dust indicators (DDIs) has been required by law at construction sites.[1]

On the other hand, there is not enough awareness of health care at construction sites in developing countries, despite high demand for tunnel construction. To avoid serious health hazards, such as in the case of Japan, the promotion of health awareness among workers and the prevalence of dust monitoring are fundamental. However, dust measuring and monitoring by traditional techniques is expensive in these countries. Furthermore, current dust measuring methods present other problems, such as the time required for data calibration because of variable monitoring conditions.

In Chapter 3, a new dust monitoring system using mobile phone was applied to measure the dust concentration at an Indian Metro construction site. This method is improved by introducing innovative techniques that can make use of smartphone cameras because the performance of mobile phone cameras has improved significantly. This mobile monitoring system was implemented at the Bangalore Metro construction site. Because the construction site was not underground, but was an open cut tunnel under sunshine, a dust monitoring chassis box was developed to get flash pictures, which are used for internal processing to quantify the dust density. The result shows that this method needs some improvement in sustained accuracy for long-time monitoring and a flexible calibration system for changing conditions.

In this chapter, the dust measurement system utilising smartphones is explained briefly, and then its problems are clarified. A simple dust monitoring system using video image processing and dust monitoring with IP (Internet Protocol) cameras are presented as a solution to the problems mentioned above.

4-2 Addressing real problems regarding construction dust monitoring by use of mobile phone cameras

(1) Problems caused by the dust monitoring box

There were two main problems with the installation of the DMS-S and the dust monitoring box at the open excavation site (Photo 4-1): occasional outlier data and recording constant values from a certain point. Both problems impair accuracy in the measurements and are related to the dust monitoring box. Furthermore, when dust monitoring using one smartphone faces the latter issue, re-calibration is required, which causes time consumption and delay in the monitoring schedule. The details and possible causes are described below.

Photo 4-1 Dust monitoring box at the open excavation site

a) Outlier data

Figure 4-1 shows the measurement results by both the DDI and the DMS-S. Although the data have a similar trend from the first to the third measurements, the fourth measurement indicates that the data trend obtained by DMS-S is much higher than that obtained by DDI. For the fourth measurement, the flash photograph by the smartphone showed a large white spot in the upper left corner (Figure 4-2). This is a large and bright scattering light that

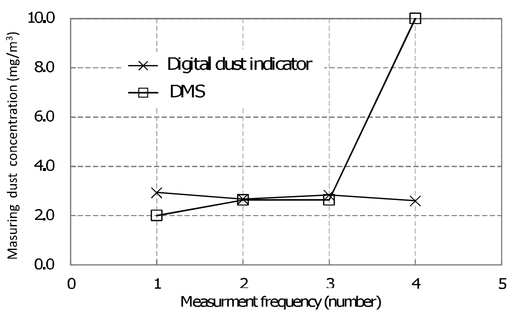


Figure 4-1 Measurement results by DDI and the DMS-S

occurred because the dust particle was too close to the lens of the camera. This enlarged particle increased the total luminance of the photograph despite the low dust concentration, leading the DMS-S to make an incorrect assessment. As a solution to this problem, the flash photograph was taken twice.

Figure 4-2 An example of the large white spot

b) Invariant data

Figure 4-3 shows the measurement result obtained by the DMS-S. After the 126th measurement, data display a constant value of 1.2 mg/m^3. The smartphone and the DDI worked normally, which means that the dust properties were not changed dynamically. One possible factor in this phenomenon was change in the blackness of the background panel that was used in the box.

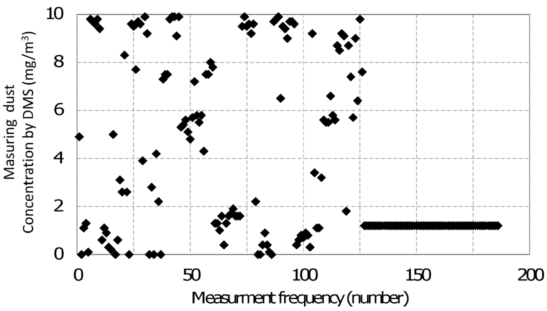


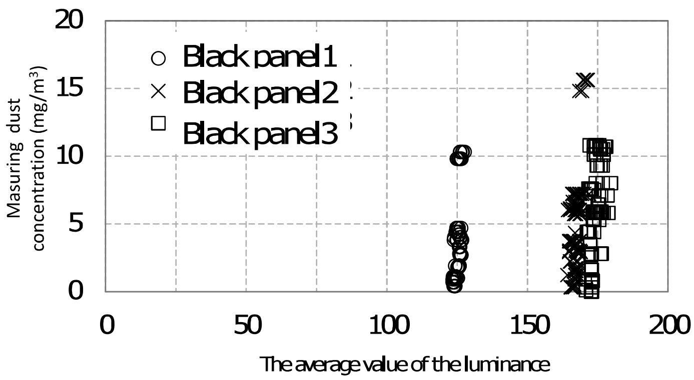
Figure 4-3 The dust concentration measured by the DMS-S

c) Background influence

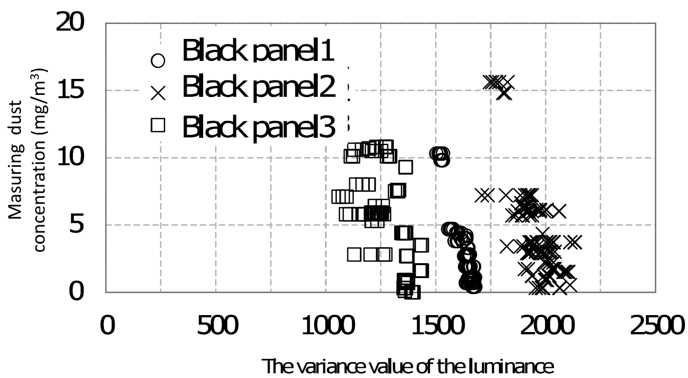
To determine the influence of the background changes, the measurement tests are conducted by use of three different types of black panel.

Figure 4-4 represents the correlation diagrams between the average and variance values of the luminance of the scattering light photograph and the data obtained by DDI. Black panel 1 is a panel immediately after spraying, black panel 2 is black panel 1 with dust applied, and black panel 3 is black panel 2 with dust wiped off. These diagrams indicate that the average value and variance value of the scattering light photograph do not depend on the dust concentration, but rather on the background conditions. Thus, the conventional DMS-S with the dust monitoring box is not suitable for long-term use because the distance between the smartphone[2] and the black panel is too short to have an influence on the monitoring data.[3]

In addition, the parameters that are used in an ANN are decided based on empirical values, depending on the feature value obtained by the flash photographs. Figure 4-5 represents the pattern diagram of the ANN used with the DMS-S. To avoid a misleading result in long-term monitoring, such as that shown in Figure 4-3, flexible calibration is required towards the variable background condition. Therefore, the feature values are required to be re-examined when an ANN is applied to the DMS-S with the dust monitoring box.



(a) The average value of the luminance



(b) The variance value of the luminance

Figure 4-4 Measured dust values in relation to average values and the variance of the luminance

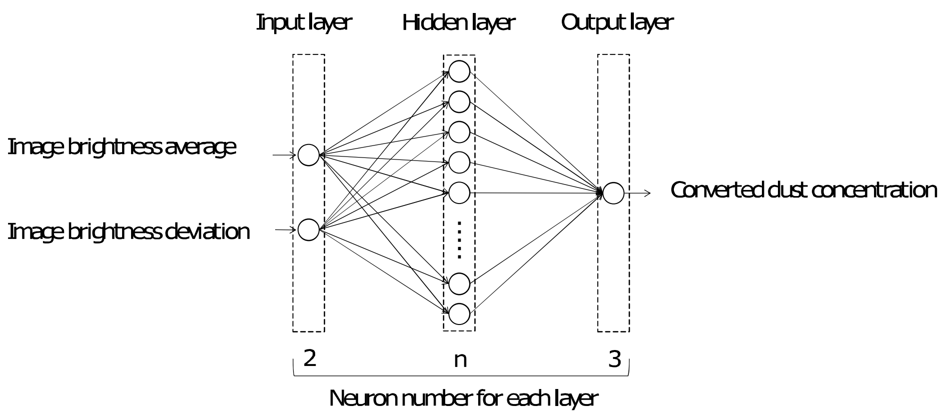


Figure 4-5 The pattern diagram of the ANN

4-3 Dust monitoring by video processing system

4-3-1 Video image

A video image consists of a three-dimensional group of data expressed in the special perpendicular coordinates x and y, and the time coordinate t. A black and white picture contains only luminance (darkness) information and is expressed as below[4]:

$$Video\ image = f(x, y, t) \tag{4-1}$$

In the case of a colour picture, the information amount becomes tripled through simple arithmetic, that is, by adding R (Red), G (Green), and B (Blue). Usually, a frame rate of 30 fps is used.

One of the advantages of a video image in a simple dust monitoring system is that it can deal with the time dimension t. It enables installation of difference processing between the flames, which are expected to reduce the influence of the change of background for long-term monitoring.

4-3-2 Scattering light image acquisition from a video image

The resolution of the video image depends on various factors, such as the quality of the equipment, the distance between the dust and the black background panel, the precision of the optical lens, the resolution of the image, and the luminance and setting of the flash of the camera. According to previous research,[5] an LED light can be used to obtain the scattering photo of the dust by use of the video function of the smartphone. In this research, the video image taken by the smartphone is combined with the IP camera image and the LED light to establish the image processing method.

4-3-3 Difference processing between flames of video

Difference processing between flames of video is a method that focuses on the luminance difference, as shown in Figure 4-6. When the image is expressed as $f(x,y,t)$, the time difference image $\Delta d(x,y,t)$ is given by Equation (4-2):

$$\Delta d(x, y, t) = |f(x, y, t) - f(x, y, t-1)| \tag{4-2}$$

where x is the horizontal pixel, y is the vertical pixel, and t is the number of the flame.

As seen in Figure 4-6, when Equation (4-2) is applied to a series of dust images, a difference in luminance is observed; that is, only the difference of the scattering light is captured.

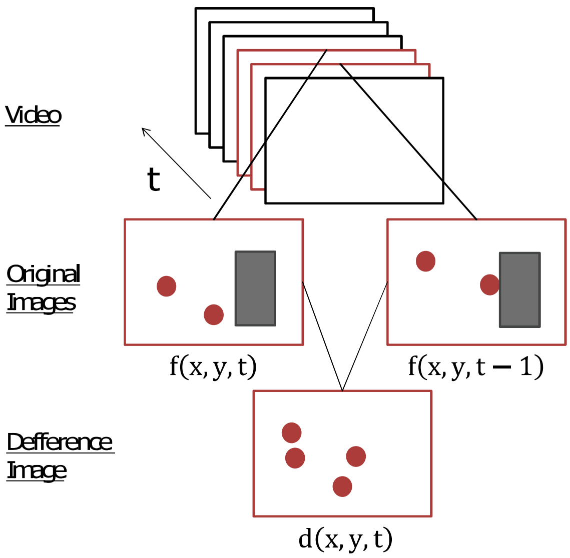


Figure 4-6 Difference processing between flames of video

Figure 4-7(b) represents an example of the difference processing between flames of video. The time difference is set to 0.1 seconds between flames. In this case, the DDI indicated the concentration value to be 8.9 mg/m^3. Although the background influence is eliminated in Figure 4-7(b), the entire image became underexposed and unclear. Also, the original image contained noise from sources such as the optical transformer, the amplifier, strain, and non-linearity of the sensor, which made monitoring more complicated. Thus, image compensation was performed.

(a-1) 0 sec (a-2) 0.1 sec (b) Difference

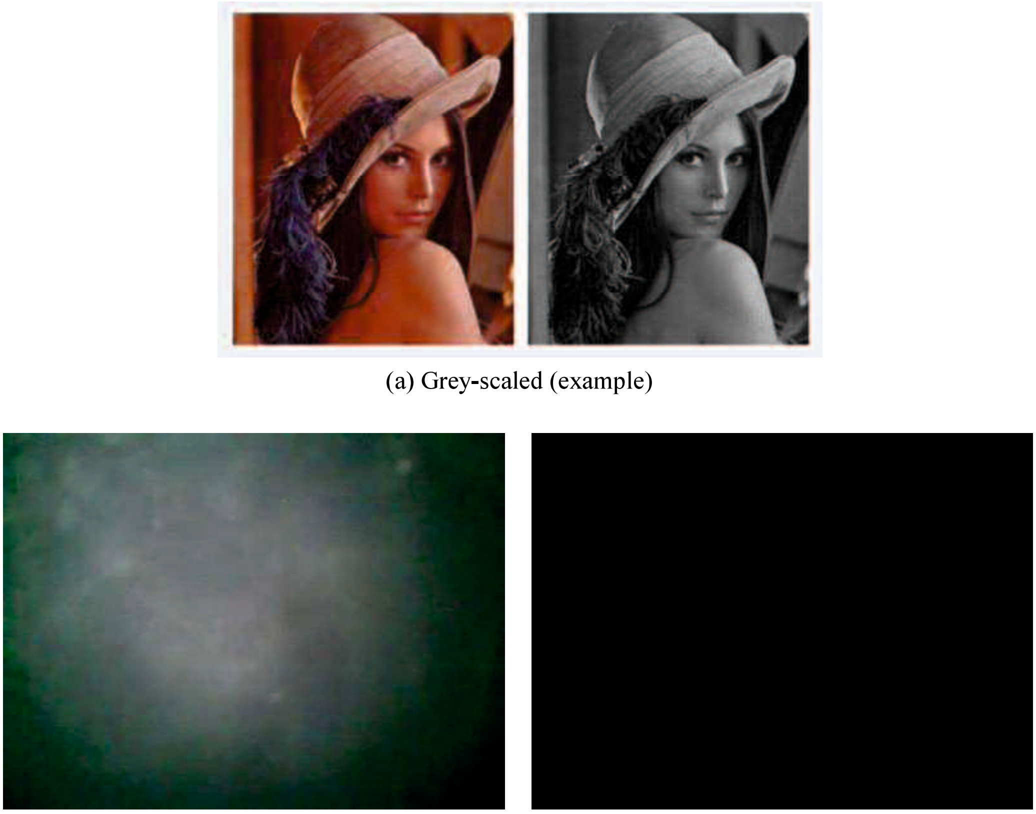
Figure 4-7 Example of difference processing

4-3-4 Image compensation

In Figure 4-7(b), each pixel is represented by three values: Red, r_{ij}; Green, g_{ij}; and Blue, b_{ij} (RGB). To simplify further processing, each RGB value is transformed to greyscale and scaled from 0 to 255 (256 levels in total). This produces a matrix a_{ij} with n rows and m columns, where n and m represent the matrix size:

$$a_{ij} = 0.2989 \times r_{ij} + 0.5870 \times g_{ij} + 0.1140 \times b_{ij} \tag{4-3}$$

Figures 4–8 indicate the greyscale image of Figure 4-7(b).



(a) Grey-scaled (example)

(b) Greyscale on dust photo

Figure 4-8 Greyscale image

a) Binarisation

Figure 4-9 shows the luminance histogram of Figure 4-8, with the number of pixels on the abscissa and the luminance on the ordinate. It represents luminance under 25, which appears quite dark on the photo image. To avoid this issue, binarisation is applied for acquisition of the proper feature value.

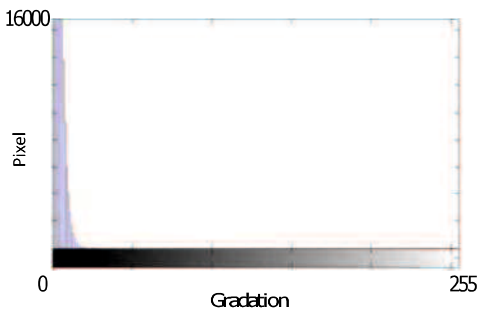


Figure 4-9 The luminance histogram of the difference processed image of Figure 4-8

Binarisation is a thresholding method in which the greyscale sample is clustered into two parts, black and white, by the threshold value. The benefit of this method is the simplicity of distinguishing between the object and the background. In this case, dust is the object and the black panel is the background. A threshold value to reveal the feature value is chosen by discrimination analysis.[6] In this method, the threshold value is selected when the separation between two distributions, which is the ratio of the variance between the classes to the variance within the class, reaches a maximum. Suppose class 1 as luminance 0~th-1, pixel n_1, average luminance $\overline{f_1}$, variance ρE_1^2 and class 2 as luminance, pixel n_2, average luminance $\overline{f_2}$, variance ρE_2^2 for the binarisation of an 8-bit greyscale picture, the variances are given as

$$\sigma_1^2 = \frac{\sum_{f=0}^{th}\left(f-\overline{f_1}\right)^2}{n_1} \tag{4-4}$$

$$\sigma_2^2 = \frac{\sum_{f=th}^{255}\left(f-\overline{f_2}\right)^2}{n_2} \tag{4-5}$$

where n_f is the number of the flame in which the luminance is f.

If the overall mean pixel is $\overline{f}$, the variance between the classes ρE_B^2 and within the class ρE_W^2 is expressed as below:

$$\sigma_B^2 = \frac{n_1\left(\overline{f_1}-\overline{f}\right)^2 + n_2\left(\overline{f_2}-\overline{f}\right)^2}{n_1+n_2} \tag{4-6}$$

$$\sigma_W^2 = \frac{n_1\sigma_1^2 + n_2\sigma_2^2}{n_1+n_2} \tag{4-7}$$

When $\frac{\sigma_B^2}{\sigma_W^2}$ is at a maximum, t is the optimum threshold value.

In this case, t = 6 is derived from Figure 4-9. The scattering light from the dust is extracted clearly. The optimum threshold value (t) shows a narrow scope, because the gradation range is a maximum of 25, as shown in Figure 4-9. The scattering light becomes dark when t shows a small value. The next processing for pre-analysis is executed at t = 6.

b) Noise reduction

Figure 4-10 shows the video images taken at dust concentration 0.0 mg/m^3 and processed by binarisation. Because there was no dust in front of the camera, all the white spots represent noise. To filter them out, a morphological operation was applied. A morphological operation is a technique to metamorphose the shape of the object, as shown in Figure 4-12.[7] In this case, the white spots are contracted to the small spots, eliminating minute spots, and then enlarged to the original size. Figure 4-13 shows the result of the morphological operation of Figure 4-10 and Figure 4-11. Comparing Figure 4-10 with Figure 4-13(a) and Figure 4-11 with Figure 4-13(b) reveals that noise was removed successfully.

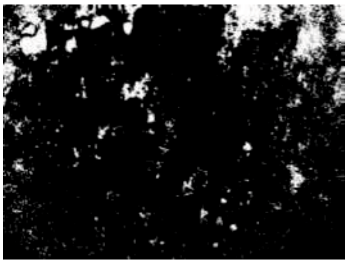


Figure 4-10 The result of binarisation

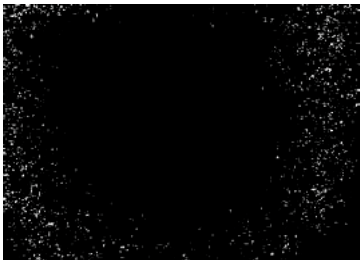
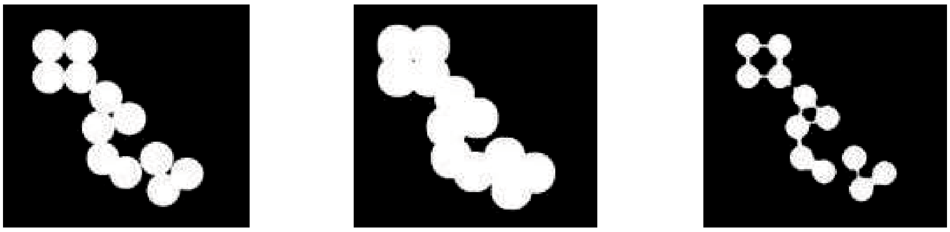


Figure 4-11 The processing result at 0.0 mg/m^3



(a) Original image (b) Enlarged process (c) Deflation process

Figure 4-12 An example of the morphological operation

(a) Applied to Figure 4-10 (b) Applied to Figure 4-11

Figure 4-13 Noise reduction process

4-3-5 Calculation of number of dust

As previously mentioned, dust particles near the camera lens caused an outlier data problem in the DMS-S. Because it is not easy to exclude this problem completely, the procedure for scattered light area division and calculating the number of dust is proposed, and the details are described below.

The scattered light area division is conducted after image compensation. In Figure 4-14, the pixel value is either 0 or 1, so the distance transformation is executed to generate a gradient. The distance transformation contains the distance between the pixel and the background.[8] The Euclidean distance shown below is used:

$$d_e = \sqrt{(i-p)^2 + (i-q)^2} \tag{4-8}$$

where d_e represents the distance between two arbitrary points (i, j).

Then, the image is divided into areas, depending on the gradient. For the area division method, the watershed algorithm is applied in this case. The watershed algorithm is a technique that interprets the greyscale pixels as a topography chart and creates a boundary along a local maximum.[9] Whereas other area division methods may produce different outcomes for the same image, depending on the arbitrary selection of the starting point and work process, the watershed algorithm deals with unique input data. Figure 4-14 represents the result of the calculation of the number of dust in Figure 4-13(a). The dust number in Figure 4-13(a) is 90; overlapped dust particles were shown separately. Figure 4-15 shows the result of the calculation for Figure 4-4, in which a dust particle near the camera lens becomes a white spot. The dust concentration is 0.4 mg/m^3. The number of the area is 1, which means the dust concentration is lower than in Figure 4-14.

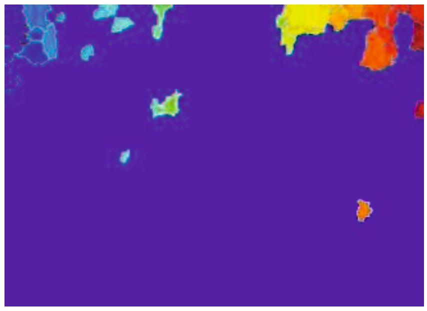


Figure 4-14 The area division image of Figure 4-13 (a)

Figure 4-15 The area division image of Figure 4-4

4-3-6 Consideration of feature values

Two feature values are obtained through the process from (4-3-2) to (4-3-5): the area (pixel) and the number of the dust scattering light. Because these values are not affected by the existence of dust near the camera lens, they are identified as suitable for long-term monitoring. The two values are multiplied and defined as a new feature value.

4-3-7 Discussion

A low new feature value means that the dust concentration is low, whereas a high value represents high concentration. Therefore, the relation between the feature value and the dust concentration can be expressed linearly when the background condition is constant. The details are presented in 4-4-2. The flowchart of a simple dust monitoring system using video images is shown in Figure 4-16.

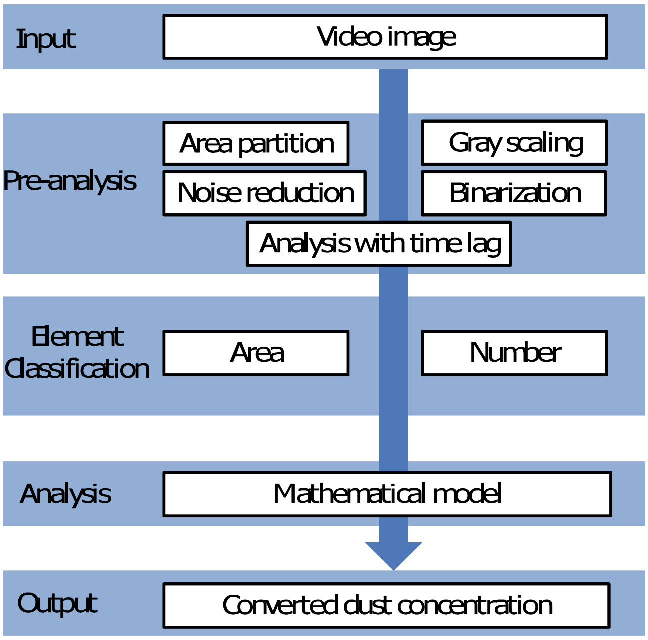


Figure 4-16 Dust concentration measuring system using video images

4-4 Dust monitoring with IP camera

4-4-1 Overview

An IP camera is a type of digital camera that can send and receive data through the network and share the information. The use of IP cameras in tunnel excavation sites became considerably popular because they enable monitoring of progress from outside of the site. In this study, an IP camera with an additional function for monitoring dust concentration was used; that is, the combination of IP camera, LED light, and aforementioned video processing programme was utilised at the site. This system is called Dust Monitoring System by IP Camera, or DMS-IPC for short (Photo 4-2).

Photo 4-2 Typical IP camera

4-4-2 Usefulness of DMS-IPC

The laboratory test shown in Figure 4-17 was carried out to examine the usefulness of a DMS-IPC based on the data obtained at the site.

The DMS-IPC was used to obtain the dust concentration data the same as the DDI. To synchronise the data, the DDI was installed near the IP camera and the data were recorded per second. The data of the DDI are presented in Figure 4-18.

The new data values, which are associated with the data from the DDI, are defined as measurement data. Measurement data are divided into two groups: the learning data for the establishment of the discriminator (276 data), and the test data for the assessment of the discriminator (84 data). The data of DMS-IPC are evaluated based on the test data.

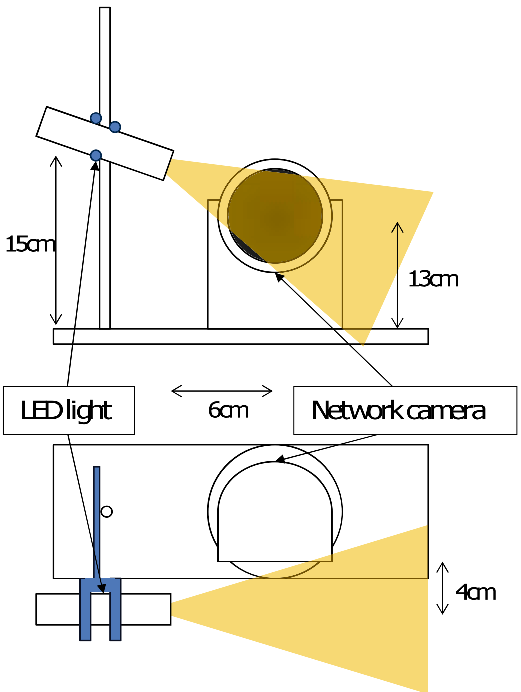
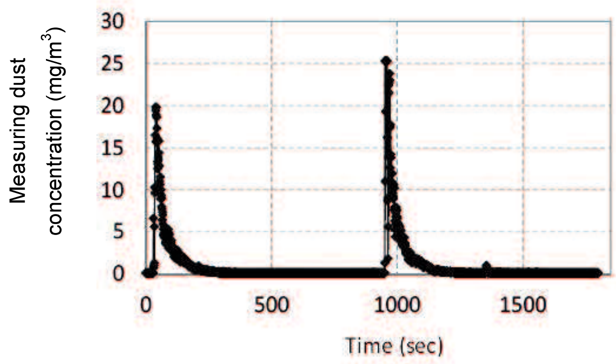
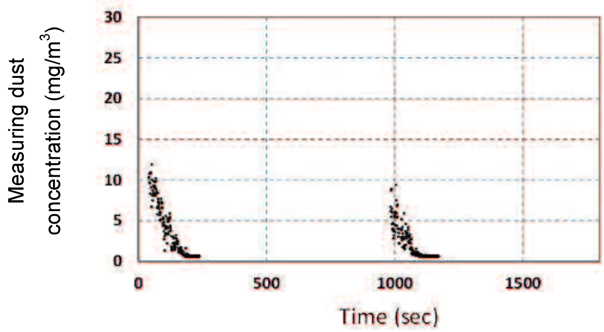


Figure 4-17 The view of the laboratory testing set



(a) Imput data



(b) Output data

Figure 4-18 The dust concentration data obtained by DDI

The correlation diagram between the new feature value obtained by learning data and the measurement data is show in Figure 4-19, and the linear approximate equation is expressed as below:

$$(Converted\ dust\ concentration) = 2.311 ln(The\ new\ feature\ value) - 21.902 \quad (4\text{-}9)$$

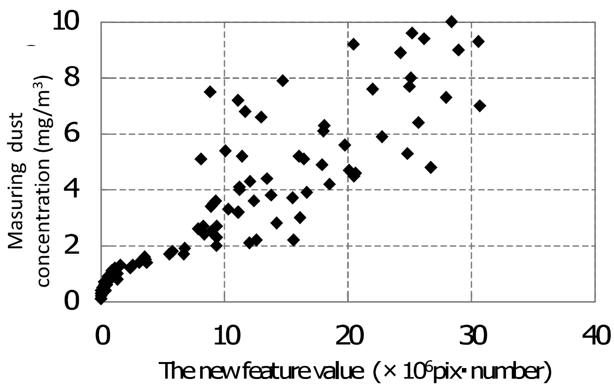


Figure 4-19 Dust values in relation to the new feature value obtained by leaning data

Figure 4-20 indicates the correlation diagram between the dust concentration value converted from the test data by Equation (4-9) and the measurement data. Then, the correlation factor is derived by Equation (4-10), which represents the relation between the converted data and the measurement data:

$$\rho = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sum_{i-1}^{n}\left(x_i - \bar{x}\right)^2}\left(\frac{\sigma_x}{\sigma_y}\right) \tag{4-10}$$

where

$\bar{x}$ is the sample mean of the dust concentration value measured by the DDI,

$\bar{y}$ is the sample mean of the dust concentration value converted by Equation (4-9),

σ_x is the standard variation of the dust concentration value measured by the DDI, and

σ_y is the standard variation of the dust concentration value converted by Equation (4-9).

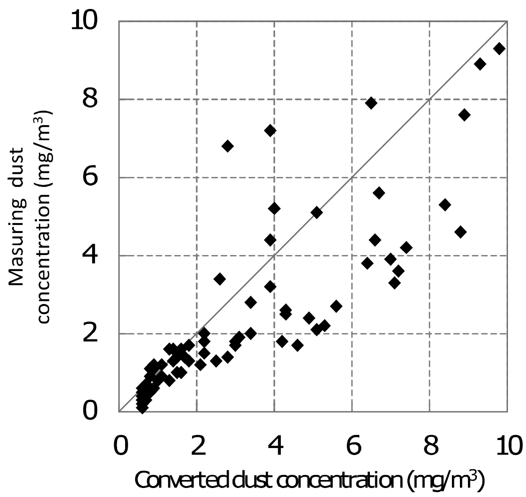
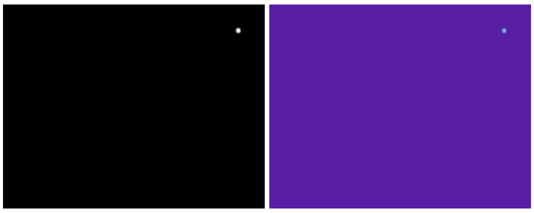


Figure 4-20 The correlation of dust values by DDI and Equation (9)

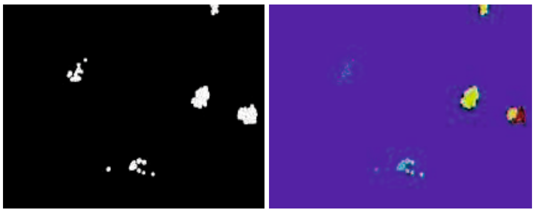
A correlation factor ρ of approximately 1.0 indicates high accuracy, whereas that over 0.8 is regarded as a good value in general. The correlation value obtained from Figure 4-20 is 0.85, which represents good agreement.

Figure 4-21 shows the results of extraction of the dust scattering light area. The images match the measurement data, and the utility of the DMS-IPC is confirmed.



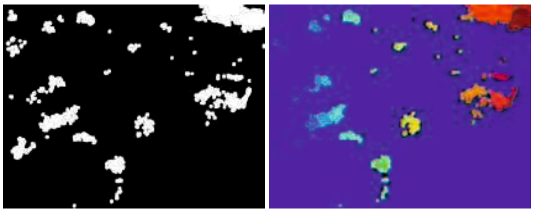
Area of the dust: 112 pix   Number of dust: 1

Dust concentration value 0.1 mg/m^3



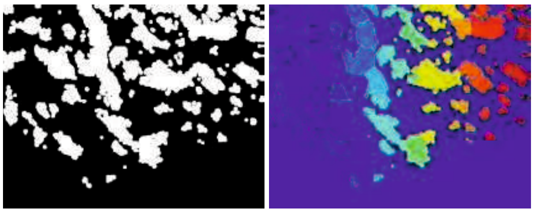
Area of the dust: 5697 pix   Number of dust: 23

Dust concentration value 0.8 mg/m^3



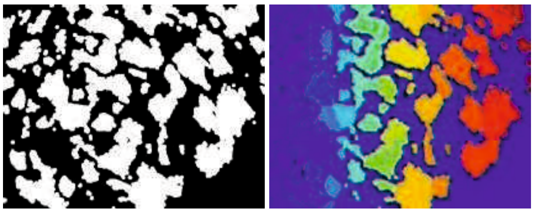
Area of the dust: 30427 pix   Number of dust: 95

Dust concentration value 4.0 mg/m^3



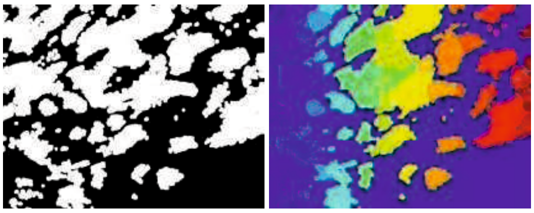
Area of the dust: 89602 pix   Number of dust: 155

Dust concentration value 5.1 mg/m^3



Area of the dust: 140460 pix   Number of dust: 160

Dust concentration value 7.7 mg/m^3



Area of the dust: 145651 pix   Number of dust: 201

Dust concentration value 9.4 mg/m^3

Figure 4-21 The results of extraction of the dust scattering light area

4-5 Future suggestions for dust monitoring with IP cameras

Some real problems are apparent in the case of dust monitoring management by use of mobile phones. The dust monitoring system that utilises IP cameras was developed to solve these problems. As another suggestion, dust monitoring by use of IP camera will be applied at construction sites. The image of future dust monitoring is shown in Figure 4-22.

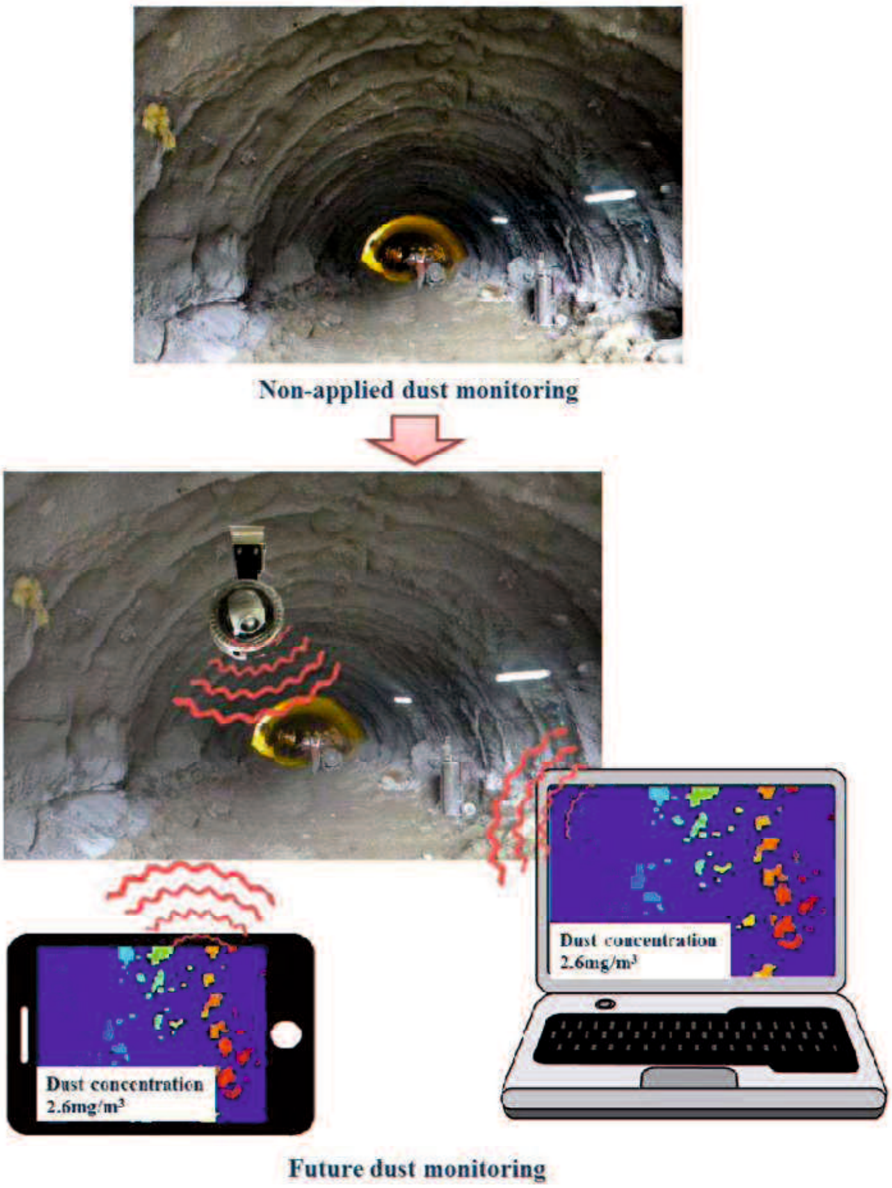


Figure 4-22 The image of future dust monitoring

Applying a monitoring system that makes use of IP cameras is simple for construction work. As the monitoring of dust concentration becomes standardised, the protection of health with dust masks will result in better environmental conditions in developing countries.

Reference

1) M. Shinji and N. Kishida: The Practical Density Measurement of Suspended Sprayed Concrete Dust using Artificial Neural Network, *Journal of Japan Society of Civil Engineers*, Ser.G(Environment Research), Vol.66, No.4, pp.194-200, 2010, (in Japanese).
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6) N. Otsu: A Threshold Selection Method from Gray-Level Histograms, *IEEE Transactions on Systems, Man and Cybernetics*, Vol.9, No.1, pp.62-66, 1983.
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8) Y. Hirano and J. Toriwaki: Methods for Structural Analysis of Digital Figures Using Distance Transformation, *MEDICAL IMAGING TECHNOLOGY*, Vol.20, No.1, 2002, (in Japanese).
9) F. Meyer: Topographic Distance and Watershed Lines, *SIGNAL PROCESSING*, Vol.38, pp.113-125, 1994.

Chapter 5

IMPROVEMENT AND SUGGESTION FOR ENVIRONMENT MANAGEMENT

5-1 Demonstrating the effectiveness and impact of awareness campaigns

The monitoring procedure, management system, training, and observation regrading environmental management in the case of dust monitoring were carried out at the construction site, as shown in Chapter 3. To become widely used for environmental management in developing countries, the effectiveness and impact of the awareness campaign must be demonstrated. As the awareness campaign, it is keypoint to share vision with the client, academic association, and government. In this section, the executing actions regarding the awareness campaign are shown and the effectiveness verified to improve environmental management.

Presentation and information activity are required for the awareness campain. As one example, a pamphlet regarding dust control in India has been issued, as shown in Figure 5-1. More than 5,000 pamphlets have been distributed since 2011.

(a) Front page (b) Back page

Figure 5-1 Pamphlet regarding safety and environmental management for awareness campaign at Bangalore Metro

Some presentations regarding dust monitoring were conducted for the client before the project began, as shown in Photo 5-1. Additionally, the workshop was held after the JICA Project, with representatives from other Metro clients in India (Delhi Metro, Mumbai Metro, Chennai Metro, and Korkata Metro.), from Metro clients in other countries (Bankok Metro, Jakarta Metro, and Dakka Metro), and from the Urban Development Ministry in India, as shown in Photo 5-2.

Photo 5-1 Explanation to client before project

(a) Workshop for presentation

(b) Workshop site visit

Photo 5-2 Workshop for presentation and site visit

The above process shows the effectiveness and impact of the awareness campaign regarding environmental improvement. As another key point, the transfer work is important to the client and contractor and will be continued. The workshop regarding environmental management was held for representatives of the client, the Indian Government, and other Indian Metros. Additionally, the DVD-ROM that shows the process of dust monitoring and management was issued to improve the environmental management of future projects (See Photo 5-3).

Photo 5-3 Procedure of dust monitoring and management on DVD-ROM

5-2 Improvement for environmental management

The environmental condition is poor at the actual construction site in India, as shown in Photo 5-4. The process regarding improvement of environmental management is demonstrated based on the application of by dust monitoring.

Photo 5-4 Poor environmental condition at the Indian construction site

Preliminary condition

As shown in Chapter 2, the current status is mentioned regarding the environmental specification/guideline in India. The specification/guideline for dust control is not applied to construction work in India at present, as shown in Table 5-1. Additionally, the environmental requirements by government/authority are in confusion. Consequently, the environmental monitoring and control plan issued by the contractor is not effective for environmental improvement. Some of the environment actions regarding air quality by the contractor are shown in Figure 5-2. The plan does not include the control/target value of dust concentration. Actually, the plan does not show the implementing action regarding dust control. The actual environmental condition is not improved at the construction site.

Table 5-1 Comparison of administrative norms between developed and developing countries for construction work

	Construction site	Remarks
Developed Country (Japan)	less than 3 mg/m^3	
Developed Country (Norway)	10 mg/m^3	total dust (all dust < 10μm)
	5 mg/m^3	respirable dust (75% of all dust < 5μm)
Developping Country (India)	No specification	

(excerpt from "Environmental Monitoring and Control Plan " issued by the contractor)

Control of Dust & Air Emission except from "Environmental Monitoring and Control Plan – Air Quality".

- Using proper equipments shall control air emissions & machines equipments maintenance should be carried out at regular interval.
- Every day morning before the site operation starts sprinkle water to the entire site.
- The point where the cement is transferred or mixer shall be covered with Gunny bags or plastic sheet in order to prevent the accumulation of cement dust particles.
- While sprinkling the water, the quantity of water used should not exceed that what is required to control the dust and the concerned person should make it sure that the water used should not affect the Housekeeping of site.
- The Engineers working at site & Safety personnel should make it sure that the sprinkling is done in a proper manner.
- Every two hours this cycle should be continued so that dust can be under control.
- Sprinkle water on top of the metal/coarse aggregated which will also help in settling the dust while transferring metal for concreting/batching Site Plant/crusher.

Figure 5-2 Some of the environment actions regarding air quality issued by the Contractor[2]

First step of environmental management

Chapter 3 shows that dust monitoring by use of mobile phone is effective in improving the environmental condition at the construction site in India. The actual environment management was carried out based on dust monitoring. The environmental training was carried out at the construction site. Additionally, the guide note was applied according to the instruction of the JICA team (Photo 5-5 and Figure 5-3).

Photo 5-5 Environmental training at the Bangalore Metro construction site

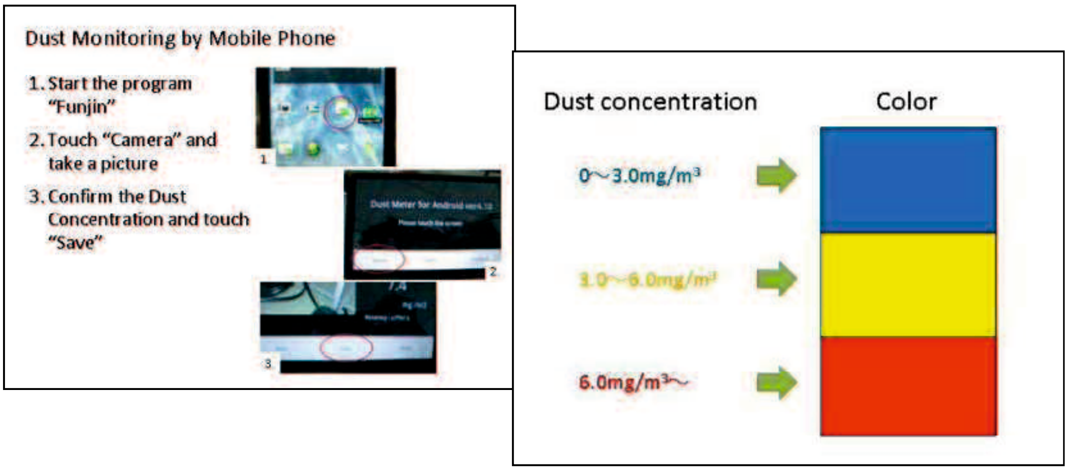


Figure 5-3 Guide note issued by the JICA team

<u>Second step of environment management</u>

The most important item is to apply the environmental management system at the site. After the JICA project, the contractor has applied the dust monitoring procedure at the construction site, as required by the BMRCL.

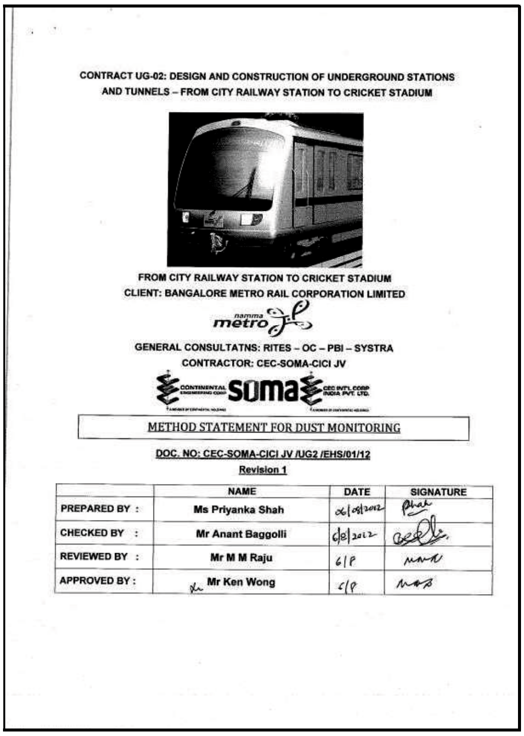
The method statement for dust monitoring was issued by the contractor (Appendix-2). The main purpose of the method statement is mentioned below. For reference, the issued letter by the contractor, with attention to the client (BMRCL), is shown in Figure 5-4, and the checklist for site management was issued, as shown in Figure 5-5.[3]

"Purpose and over view" expert from method statement for dust monitoring

(issued by Contractor in Aug. 2012)

The Bangalore Metro UG-2 Project consists of construction of 4.8 km of underground railway system including twin bored tunnels and four stations from Magadi Road to Cricket Stadium Station. The tunnels will be bored in the heart of Banagalore by Tunnel Boring Machines.

- ✓ The purpose of this document is to outline the methodology for the monitoring of dust level in and around the Area of construction works of the underground Metro Railway Stations and the tunnels or within the zone of influence of either the eastbound or the westbound tunnels of Metro Corridor Contract UG-2..
- ✓ To protect the workplace and public and provide a safe working condition.



CONTRACT UG-02: DESIGN AND CONSTRUCTION OF UNDERGROUND STATIONS AND TUNNELS – FROM CITY RAILWAY STATION TO CRICKET STADIUM

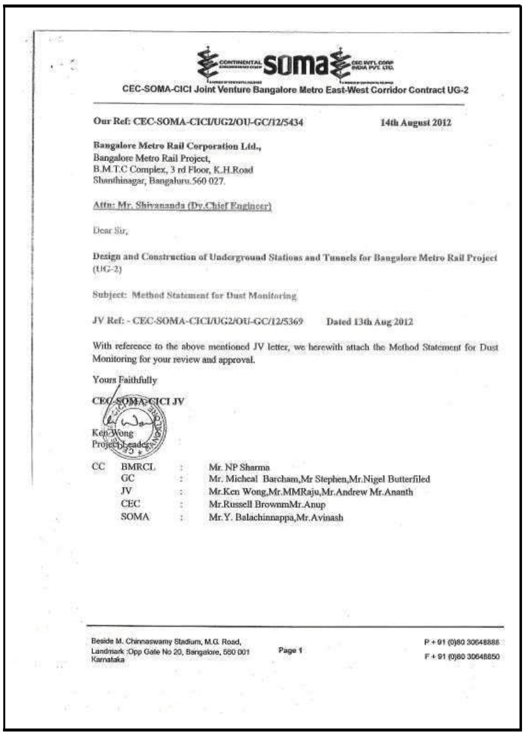
FROM CITY RAILWAY STATION TO CRICKET STADIUM
CLIENT: BANGALORE METRO RAIL CORPORATION LIMITED

GENERAL CONSULTATNS: RITES – OC – PBI – SYSTRA
CONTRACTOR: CEC-SOMA-CICI JV

METHOD STATEMENT FOR DUST MONITORING

DOC. NO: CEC-SOMA-CICI JV /UG2 /EHS/01/12
Revision 1

	NAME	DATE	SIGNATURE
PREPARED BY :	Ms Priyanka Shah	06/08/2012	Shah
CHECKED BY :	Mr Anant Baggolli	6/8/2012	[illegible]
REVIEWED BY :	Mr M M Raju	6/8	[illegible]
APPROVED BY :	Mr Ken Wong	6/8	[illegible]



CEC-SOMA-CICI Joint Venture Bangalore Metro East-West Corridor Contract UG-2

Our Ref: CEC-SOMA-CICI/UG2/OU-GC/12/5434 14th August 2012

Bangalore Metro Rail Corporation Ltd.,
Bangalore Metro Rail Project,
B.M.T.C Complex, 3 rd Floor, K.H.Road
Shanthinagar, Bangaluru.560 027.

Attn: Mr. Shivananda (Dy.Chief Engineer)

Dear Sir,

Design and Construction of Underground Stations and Tunnels for Bangalore Metro Rail Project (UG-2)

Subject: Method Statement for Dust Monitoring

JV Ref: - CEC-SOMA-CICI/UG2/OU-GC/12/5369 Dated 13th Aug 2012

With reference to the above mentioned JV letter, we herewith attach the Method Statement for Dust Monitoring for your review and approval.

Yours Faithfully

CEC-SOMA-CICI JV

Ken Wong
Project Leader

CC BMRCL : Mr. NP Sharma
GC : Mr. Micheal Barcham,Mr Stephen,Mr.Nigel Butterfiled
JV : Mr.Ken Wong,Mr.MMRaju,Mr.Andrew Mr.Ananth
CEC : Mr.Russell BrownmMr.Anup
SOMA : Mr.Y. Balachinnappa,Mr.Avinash

Beside M. Chinnaswamy Stadium, M.G. Road,
Landmark :Opp Gate No 20, Bangalore, 560 001
Karnataka
Page 1
P + 91 (0)80 30648888
F + 91 (0)80 30648850

Figure 5-4 Letter regarding dust monitoring issued by the contractor[3]

APPENDIX – 1

DUST MONITORING CHECK SHEET

							Mob No:		Box:	
			Dust Concentration, mg/m³							
Date	Time	Location	1st	2nd	3rd	4th	5th	Average	Work Item	Remarks

Figure 5-5 Check sheet for dust monitoring[3]

Based on the measured dust concentration volume, the dust mask is applied at the construction site. The instruction regarding dust measuring and dust masks has been carried out by the contractor since August 2012, as shown in Photo 5-6.

Photo 5-6 Promotional photo regarding dust measuring and mask

Environmental training has carried out by the contractor at the site, as shown in Photo 5-7.

Photo 5-7 Environmental training by the contractor at the Bangalore Metro site

To issue the letter means that the contractor has responsibility of dust control. After issue of the method statement, the contractor is applying the check sheet to measure the dust concentration daily, as shown in Figure 5-4. The management system for dust control was transferred from supervisor (JICA Team) to the implementing agency (BMRCL) and the contractor for the developing country. The management system has been executed by the BMRCL and the contractor. The environmental improvement is shown at the actual project site of the Bangalore Metro.

5-3 In the case of safety improvement in India

Previously, the safety condition was quite poor at Indian construction sites, as shown in Photo 5-8 and Photo 5-9.

Photo 5-8 Typical construction site in a city in India

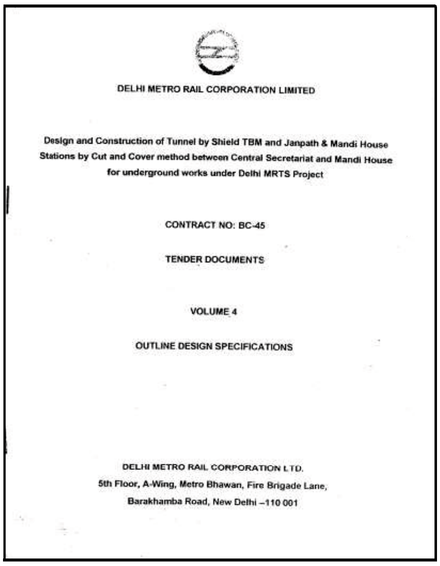
Photo 5-9 Poor safety condition at a construction site in India

Much safety instruction and application by supervisors in developed countries, including Japan, have been carried out at the Indian Metro Project.[1] Safety management is greatly improved at the Metro construction site, as shown in Photo 5-10. Additionally, a new technology called On Site Visualization (OSV) monitoring, developed by a Japanese university for safety management at the Delhi Metro Project, was applied. The displacement of the ground, the inclination of existing buildings, and the pressure of struts are measured at the construction site during excavation work. The measurement data are indicated by coloured lights of red, yellow, and blue, as shown in Photo 5-11. The safety management, including OSV monitoring, is effective.

Photo 5-10 Safety training at the Delhi Metro construction site[1]

Photo 5-11 OSV monitoring at the construction site of the Delhi Metro Project[1]

As the result of demonstrating the effectiveness and impact of the awareness campaign regarding safety management, the specification of the next phase of the project was issued, including OSV monitoring and developed safety management, as shown in Figure 5-6 and Figure 5-7.



DELHI METRO RAIL CORPORATION LIMITED

Design and Construction of Tunnel by Shield TBM and Janpath & Mandi House Stations by Cut and Cover method between Central Secretariat and Mandi House for underground works under Delhi MRTS Project

CONTRACT NO: BC-45

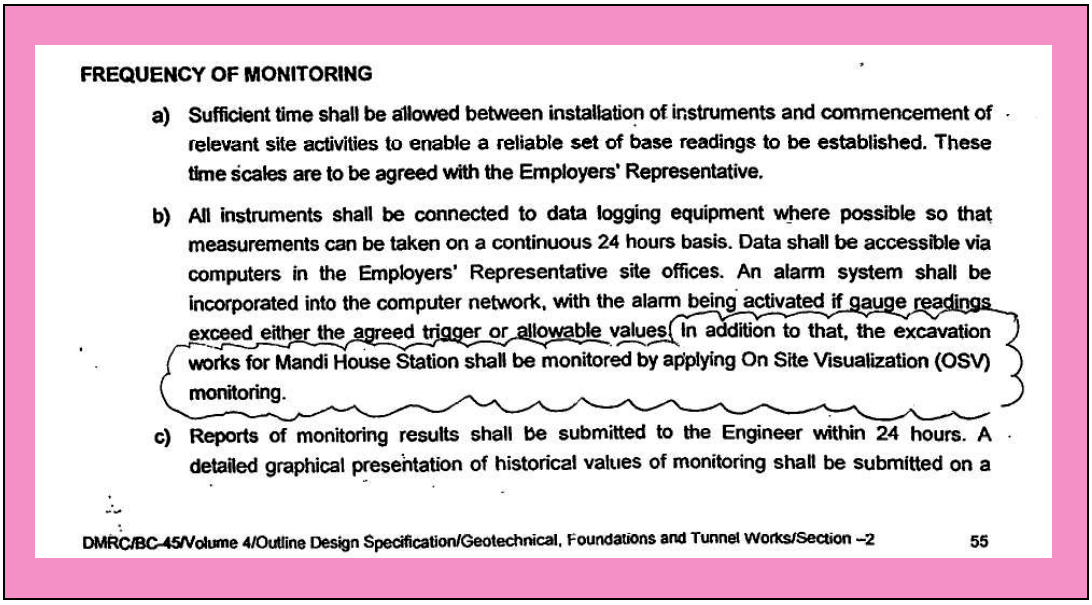
TENDER DOCUMENTS

VOLUME 4

OUTLINE DESIGN SPECIFICATIONS

DELHI METRO RAIL CORPORATION LTD.
5th Floor, A-Wing, Metro Bhawan, Fire Brigade Lane,
Barakhamba Road, New Delhi – 110 001

Figure 5-6 Construction specification of Delhi Metro Project – Phase-III in 2011



FREQUENCY OF MONITORING

a) Sufficient time shall be allowed between installation of instruments and commencement of relevant site activities to enable a reliable set of base readings to be established. These time scales are to be agreed with the Employers' Representative.

b) All instruments shall be connected to data logging equipment where possible so that measurements can be taken on a continuous 24 hours basis. Data shall be accessible via computers in the Employers' Representative site offices. An alarm system shall be incorporated into the computer network, with the alarm being activated if gauge readings exceed either the agreed trigger or allowable values. In addition to that, the excavation works for Mandi House Station shall be monitored by applying On Site Visualization (OSV) monitoring.

c) Reports of monitoring results shall be submitted to the Engineer within 24 hours. A detailed graphical presentation of historical values of monitoring shall be submitted on a

DMRC/BC-45/Volume 4/Outline Design Specification/Geotechnical, Foundations and Tunnel Works/Section –2 55

Figure 5-7 Construction specification with description of OSV monitoring

5-4 Suggestion of monitoring and management for environmental improvement

The safety protection is standardized, such as helmet, safety jacket, and safety shoes in Indian Metro projects. There is poor attention regarding the environmental management for construction work, including dust protection, at present. The matter of air pollution was reported by mass media in India recently. Based on the mass opinion against environmental condition, especially in urban areas, the protection mask against dust pollution will be standardized by the Bangalore Metro Railway Corporation Limited (BMRCL) as a leading company in India.

The awareness campaign is effective for environmental management for construction work. The installation of sign boards, the distribution of pamphlets, and the exposition training were carried out. The awareness campaign is effect for improvement of environmental management at the Bangalore Metro Project.

This environmental effort against dust pollution, including measuring, documentation, and training, first applied for to construction work in India is an example that can be followed. The application of dust monitoring has been considering by Indian Authority after the JICA Project. The guideline for dust control has been studied for road construction work by the Central Road Research Institute in India since March 2013.

However, not only dust management items but also other management items shall be in attention as below. It is recommended that the other items also be standardized.

- Handling of chemicals
- Noise control
- Dust control
- Waste management

In this study, one process is shown for environmental improvement. For more improvement of environmental management, this study can support the establishment of a specification/guideline that is the same as in developed countries, as shown in Photo 5-12.75

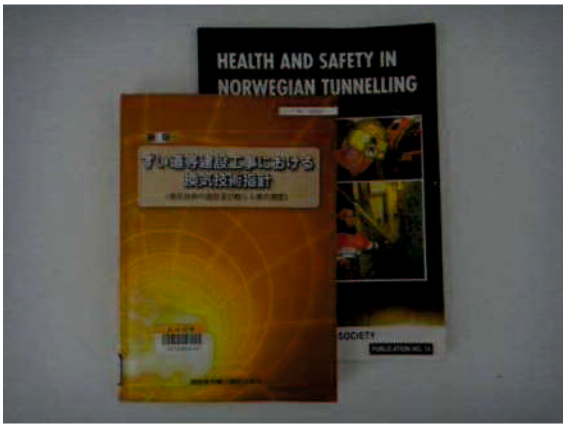


Photo 5-12 Specification/guideline in developed countries[4, 5]

The findings of improvement and suggestion for environmental management are shown below.

- The awareness campaign is as important to improving the environmental condition as technology and management.
- One example of the process to establish the specification/guideline was shown.
- The environmental specification/guideline shall be established in India based on our suggestion.

Reference

1) Japan International Cooperation Agency(JICA): Special Assistance for Project Implementation (SAPI) applying the Monitoring Method by On Site Visualization at Delhi Metro Construction Sites, (*Japan International Cooperation Agency*), 2010.
2) CEC – SOMA – CICI JV FOR BANGALORE METRO PROJECT: Environmental Management Plan – Environmental Monitoring and Control Plan Air Quality, 2012.
3) CEC – SOMA – CICI JV FOR BANGALORE METRO PROJECT: Method Statement for Dust Monitoring for Bangalore Metro Project, 2012.
4) Japan Construction Occupational Safety and Health Association: Zuidotou kensetsukouji ni okeru kanki gijutu shishin, (J*apan Construction Occupational Safety and Health Association*), 1991, (in Japanese).
5) Norway Tunneling Society: Health and Safety in Norwegian Tunneling, (*Norway Tunneling Society Publication No.13*), 2004.

Chapter 6
CONCLUSION

There is not enough awareness of health care at construction sites in developing countries, despite a high demand for construction work. To avoid serious health hazards, the promotion of health awareness among workers and the prevalence of dust monitoring are fundamental.

The problem and scope of this study are shown below.

Actual problem in the case of India

- No monitoring of dust concentration because of expense of dust detectors
- No site management for dust monitoring
- No specification regarding environmental conditions, including dust monitoring for construction work

Based on these actual problems, this study was executed as shown below.

Scope of this study

- Applied dust monitoring at construction site by use of the dust detector with low cost and ease of handling
- Suitable site management to improve the environmental conditions based on dust monitoring
- Suggested specification/guideline regarding environmental conditions for construction work

For clear understanding, the major points are discussed below.

Current status in India

As for the current status regarding environmental conditions in India, the specifications/guidelines for dust control are not specified for construction work. Additionally, the environmental requirements of government/authorities are subject to confusion. The actual environmental conditions have not been improved at construction sites to date.

Execution of environmental management in the case of dust monitoring at the site

For improvement of environmental conditions, a new dust monitoring method utilising digital cameras to measure the dust concentration at construction sites was introduced by the JICA team. Further, these methods have been improved by application of innovative techniques utilising smartphone cameras, because the performance of mobile phone cameras has improved significantly. In particular, actual environmental management was carried out based on dust monitoring. The presentation for site managers and the environmental training of workers were carried out at the site. Additionally, installation of sign boards at the site and distribution of pamphlets were carried out as part of the awareness campaign. The site demonstrations (including dust monitoring), site management, and awareness campaign are effective in improving environmental management at the Indian Metro site.

Transfer to client and contractor

As a key point, the transfer work is important to the client and the contractor and will be continued. A workshop regarding environmental management was held for representatives of the client, the Indian Government, and other Metro Project stakeholders.

Actual application after transfer

The most important item is the application of the environmental management system at the site. The contractor has implemented dust monitoring at the site. Based on the measured dust concentrations, dust masks are now in use at the construction site. The instruction regarding dust measurement and the use of dust masks has been carried out by the contractor since August 2012. Deserving special mention, the environmental training has been carried out by the contractor at the site.

Improved dust monitoring method

Some real problems are apparent in the case of dust monitoring management by use of mobile phones. The dust monitoring system utilising IP cameras was developed to solve these problems. Applying the method for dust monitoring is easy at construction sites.

Suggestion of monitoring and management for environmental improvement

Applying the IP camera monitoring system makes measuring easy to implement for construction work. As monitoring of dust concentrations becomes standardised, the protection of health with dust masks will result in better environmental conditions in developing countries.

Dust management, including measurement, documentation, training, and the awareness campaign, was applied to construction work in India. Its advantageous effects are shown in this study in terms of environmental improvement. This example shall be applied for environmental improvement in other developing countries.

Conclusions

The conclusions of this study, regarding improvements in environmental management efficiency in developing countries, are shown below.

1. The actual considerations appeared to be no specification and site management regarding dust monitoring for construction work based on current status studies.
2. The case study, including dust monitoring and site management, was carried out at an Indian construction site by use of mobile phone. The results show that application of these methods can improve environmental conditions.
3. The technology for dust monitoring was improved by use of IP cameras, which offer increases in convenience and availability compared to traditional methods.
4. The awareness campaign is one of the key items designed to improve environmental conditions.
5. A process to establish suitable environmental specifications/guidelines has been shown in this study.

It is very important not only to use new technology but also to find new applications for existing technology. Finalised Indian guidelines will be issued based on this study after many discussions and other applications in future.

In this study, one process in particular has been investigated for its environmental improvement potential. For more extensive improvements in environmental management, including not only dust management but also noise, vibration, and waste management, the results and processes of this study can contribute to the establishment of specifications/guidelines for developing countries, similar to those issued by developed countries.

APPENDIX

APPENDIX - 1

Title : Environmental management Plan – Environmental Monitoring and Control Plan Air Quality for Bangalore Metro Project, by CEC-COMA-CICI joint venture Bangalore Metro East-West Corridor Contract UG-2, 27 March 2012.

APPENDIX – 2

Title : Method Statement for Dust Monitoring for Bangalore Metro Project, by CEC-COMA-CICI joint venture Bangalore Metro East-West Corridor Contract UG-2, 06 August 2012.

APPENDIX – 3

Title : Dust Monitoring Survey for Bangalore Metro Project

(SET A) for Site Engineers / Officers

(SET B) for Workers

(SET C) for Road Users

1	PURPOSE	Purpose of this procedure is to monitor and control the Air emission from equipment, machines and operations.
2	SCOPE	The scope includes the site where the environmental management system is implemented. Air emissions are to be measured Once twenty four hours sample monthly.
3	RESPONSIBILITY	Engineer-In- Charge
4	PROCEDURE	➢ Identify the probable air emission equipment, machines and operations. The site should maintain their own list of equipments and machines. ➢ Carry out the measuring/sampling at the sources at different levels and take one 24 hrs. samples monthly. ➢ If the dust level is observed above the prescribed values by the legislative requirements or by the site initiate the controlling action. **Control of Dust & Air Emission** ➢ Using proper equipments shall control air emissions & machines equipments maintenance should be carried out at regular interval. ➢ Every day morning before the site operation starts sprinkle water to the entire site. ➢ While transferring the fine aggregate/metal in dumpers make it sure that it is covered with tarpaulins in order to control the dust and maintain free board at least 300 mm. ➢ The point where the cement is transferred or mixer shall be covered with Gunny bags or plastic sheet in order to prevent the accumulation of cement dust particles. ➢ While sprinkling the water, the quantity of water used should not exceed that what is required to control the dust and the concerned person should make it sure that the water used should not affect the Housekeeping of site. ➢ The Engineers working at site & Safety personnel should make it sure that the sprinkling is done in a proper manner. ➢ Every two hours this cycle should be continued so that dust can be

under control.

- If possible landscaping should be carried out with minimum cost since grass can prevent dust. This can be practiced looking into the soil conditions of the site.
- Sprinkle water on top of the metal/coarse aggregated which will also help in settling the dust while transferring metal for concreting/ batching Site/Plant/crusher.
- The approach road to the site can also be watered using sprinkler system to reduce the dust.
- The top of the fine aggregate/sand can be sprinkled with water in a mild way to ring down the dust under control.

Source of Air Pollution:

The main pollutants, which will come out from different activities, would be suspended particulate matter (SPM) and repairable suspended particulate matter (RSPM). The main sources of Air Pollution are:

- The dust coming out from site activities i.e. Excavation / movement of vehicle/equipments.
- Dust generated due to material transportation.

Mitigation Measures:

Control Requirement during Transport of Material.

Transport of material from one place to another generates air pollution, which degrades the quality of the area. To minimize visible particulate matter from being deposited upon roadways. It includes removal of particulate matter from equipment. Before in operation, all equipment should be well maintained Vehicle cleaning facility/wheel washing will be provided. Wherever required the vehicles carrying dust generated material will be covered to avoid fly over of the dust.

Control Requirements at Dumping Sites:

We shall place material in a manner that will minimize dust production. Material shall be stabilized by watering or other accepted dust suppression techniques.

The heights from which materials are dropped shall be the minimum practical height to limit fugitive dust generation.

We shall stockpile the material in the properly designed suitable location, with suitable slopes. The speed of the vehicles moving in this area will be controlled through strict speed limits to avoid dust generation

During dry weather, dust control methods must be used daily especially on windy, dry days to prevent any dust from blowing. Provide water sprinklers that are required for dust control use. Dust control activities shall continue during work stoppages if required.

Control of Dust on Haul Roads:

To reduce the dust generation during the Hauling operation on the Roads, Water Sprinkling Tankers shall be hired by the company. The tankers are contracted to 3prinklc water at defined intervals or all the Haul Roads in which the activities are going on. The no. of trips, frequency and areas are clearly defined and communicated to the Contractor and also to respective departments.

The driver of the tanker as per defined schedule reports to the concerned departmental supervisor of an area and the no. of trips made in a particular area is supervised by the respective departmental supervisors. Records of total no. of trips made by the tankers are maintained in the "Dust Suppression Register".

In the month each concerned department to personnel and Administration Department in the "Monthly Report" report the total number of trips made by Water Sprinkler. Effective of the Water Sprinkling tanker for suppressing the dust may also be commented by the respective department to Personnel and Administration Department, which will useful to evaluate the performance of the Sprinkling Tankers.

Control of Dust during the Construction Operations / Activities:

a) The Dust Concentration during the any Operations/Activities shall be kept to a lowest possible extent and the concerned Supervisors shall take the required action as per the requirement.

b) During such activities the PPEs (Dust mask) shall be provided to the workers.

Control of Dust in the Material storage Area:

The Material like Aggregates, Fine material etc. when stored shall be done in such a manner that during the High wind the Dust will not fly in the air. This can be done by making low height of the heaps and also making temporary barrier against the wind direction around the storage area. The Sprinkling of water around such storage area, on the Material itself (if feasible) etc. shall be carried out with the help of flexible pipe and the concerned Supervisor of such operations shall see that Sprinkling is carried out properly and regularly. A list of areas where personnel working shall wear PPEs during operation/activities is prepared for each site.

CONTINENTAL ENGINEERING CORP **SOMA** CEC INT'L CORP INDIA PVT. LTD.

CEC-SOMA-CICI Joint Venture Bangalore Metro East-West Corridor Contract UG-2

Our Ref: CEC-SOMA-CICI/UG2/OU-GC/12/5369 **06th August 2012**

RITES – OC – PBI - SYSTRA
General Consultants to BMRCL,
Underground Site Office,
Opp. Gate No.20 Chinnaswamy Stadium,
MG Road,
Bangalore 5600010

Attn: Reiko Abe (Oriental Consultant)

Dear Sir,

Design and Construction of Underground Stations and Tunnels for Bangalore Metro Rail Project (UG-2)

Subject: Method statement for Dust Monitoring

We thank you for previously providing us an opportunity to carry out dust monitoring using Android phone at our project. The JV would like to share the same equipment with other contractor to carry out the Dust Monitoring. We attach herewith the Method Statement and Checklist to be followed during the Dust monitoring. Therefore we request you to issue equipment to JV's Safety manager/Environment Engineer for our monitoring Purpose. We look forward to have your positive reply on this matter.

Yours Faithfully
CEC-SOMA-CICI JV

Ken Wong
Project Leader

CC	BMRCL:	Mr. NP Sharma
	GC:	Mr. Micheal Barcham, Mr. Nigel Butterfield, Mr Stephen Pollock
	JV:	Mr. Ken Wong, Mr.MM Raju, Mr.Anant, Ms. Priyanka Shah
	CEC:	Mr.Russell Brown
	SOMA:	Mr.Y. Balachinnappa

CONTRACT UG-02: DESIGN AND CONSTRUCTION OF UNDERGROUND STATIONS AND TUNNELS – FROM CITY RAILWAY STATION TO CRICKET STADIUM

FROM CITY RAILWAY STATION TO CRICKET STADIUM

CLIENT: BANGALORE METRO RAIL CORPORATION LIMITED

namma metro

GENERAL CONSULTATNS: RITES – OC – PBI – SYSTRA

CONTRACTOR: CEC-SOMA-CICI JV

CONTINENTAL ENGINEERING CORP · SOMA · CEC INT'L CORP INDIA PVT. LTD.

A MEMBER OF CONTINENTAL HOLDINGS · A MEMBER OF CONTINENTAL HOLDINGS

METHOD STATEMENT FOR DUST MONITORING

DOC. NO: CEC-SOMA-CICI JV /UG2 /EHS/01/12

Revision 1

	NAME	DATE	SIGNATURE
PREPARED BY :	Ms Priyanka Shah	06/08/2012	
CHECKED BY :	Mr Anant Baggolli	6/8/2012	
REVIEWED BY :	Mr M M Raju	6/8	
APPROVED BY :	Mr Ken Wong	6/8	

TABLE OF CONTENTS

Appendix:

1. Checklist/Format for Air Monitoring.

1. PURPOSE AND OVERVIEW

The Bangalore Metro UG-2 Project consists of construction of 4.8 km of underground railway system including twin bored tunnels and four stations from Magadi Road to Cricket Stadium Station. The tunnels will be bored in the heart of Banagalore by Tunnel Boring Machines.

- ✓ The purpose of this document is to outline the methodology for the monitoring of dust level in and around the Area of construction works of the underground Metro Railway Stations and the tunnels or within the zone of influence of either the eastbound or the westbound tunnels of Metro Corridor Contract UG-2..
- ✓ To protect the workplace and public and provide a safe working condition.

2. SCOPE OF WORK

This work procedure covers the procedure for monitoring dust concentration at working sites of CEC-SOMA-CICI JV /UG-2 Project which covers four stations sites viz. Cricket Stadium, Vidhana Soudha, Central College and City Railway Station and Tunnel Shaft area of Majestic East, Central College west and east shaft area, East Ramp and West Ramp area.

3. LIST OF EQUIPMENTS / MATERIALS:

Android Phone with Funjin Software, Dust Monitoring Box

4. METHODOLOGY

The operations include:

- ✓ Bring the dust Box to the Monitoring Point
- ✓ Clean dust box and Black Board (Be care not to use water)
- ✓ Set the HTC Android Mobile phone to the Dust box
- ✓ Open the box and keep it open for one minute
- ✓ Close the box
- ✓ Start the program "Funjin" on mobile
- ✓ Touch Camera and take Picture
- ✓ Confirm the Dust Concentration and touch "save" to save results.
- ✓ Write the dust density to check sheet
- ✓ Repeat this procedure 3 – 4 times at same monitoring point
- ✓ If strange monitoring Results comes, recalibration of phone required

Procedure for Re-Calibration

- ✓ Take 10 Photographs by using "Funjin" in situation that the dust concentration is 0 mg/m^3 (Confirm with Digital Dust Indicator)
- ✓ Send This photographs to Sasaki (Sasaki do the Re-calibration, make a new program "Funjin" and send it to mobile phone)
- ✓ Uninstall the old "Funjin" by "Apk Manager"
- ✓ Install the new one from G-mail
- ✓ Confirm the program works well or not
- ✓ If not, do the procedure again

5. FREQUENCY OF MONITORING

As per the contract requirement, clause 47.1.7, Dust Monitoring will be carried out at every fifteen days at regular Intervals.

6. RESPONSIBILITIES

The responsible persons and the responsibilities are listed as follows: Overall responsible for whole operations.

Project Leader:

- ✓ Overall responsible for Project

JV Safety Manager:

- ✓ Ensure works are carried out as per planning.

Site Safety Officer/ JV Environment Engineer

- ✓ Regular Monitoring of Dust level at Site

7. SAFETY PROVISION

The execution of works will strictly follow the requirements of Safety plan.

The following measures are to be strictly complied with during Dust Monitoring:

- ➢ Use appropriate PPE including Safety Helmet, Safety Shoes, High Visibility Jackets.

APPENDIX – 1

DUST MONITORING CHECK SHEET

						Mob No:		Box:		
			Dust Concentration, mg/m^3							
Date	Time	Location	1st	2nd	3rd	4th	5th	Average	Work Item	Remarks

Special Assistance for Project Implementation (SAPI) applying On Site Visualization and Dust Monitoring at Bangalore Metro construction sites

SAPI for Bangalore Metro Project utilizing Japanese ODA

Japan International Cooperation Agency

June 2011 to January 2012

SET A: Dust Monitoring Survey for Site Engineers/Officers

Name of the Surveyor:---

Location of the Survey:---------------------------------------Date of Survey:-------------Time:----------

1. Personal Details

i) Name:--- Sex: Male/Female

ii) Age:------- in years

iii) Educational Qualifications:-(a) Graduation (b) Master (c) Doctoral(d)Others (Specify)-------------------------

iv) Nature of Job :- (a) Site Engineer(b) Safety Officer (c) SM (d) CPM/DyCPM(e) Others(Specify)-----------------

v) Organization:- (a) JICA (b) GC (c) BMRC (d)SOMA (e) Others Specify:------------------------

2. Working Experience (in years)

i) Total working experience: (a) at construction site---------------- (b) other works-------------------

ii) Working experience in present organization: (a) at construction site---------------(b) other works---------

iii) Work experience at present site: --------------------

3. Dust Monitoring and Control Experience

i) Do you aware about effect of dust (a) yes (b) no ; If yes do you know the impact of dust on health yes/ no

ii) How often have you attended dust Monitoring and Control programme? : (a) Never (b)Some times (c) Often (d)Very often

iii) How often have you faced/seen any dust related incident/ problem during safety monitoring and control at site?: (a)Never(b) Some time (c) Often d) Very often

If so, pl. specify how many times:-------------------------

A) If Dust related Problems were faced (provide the following information)

- ❖ Have you met any dust related health problem in your working Site (a) Yes (b) No

If yes, provide the following Information

- ❖ What Type problem (a) Breathing difficulties (b) Nose/Throat Irritation (c) Eye Irritation (d) any other specify

If Yes, provide the following Information

- ❖ How many times:------------ When the last problem occurred (a) one week (b) Fortnight (c) month (d) one year
- ❖ Details about last health problem due to dust : (i) Minor (ii) Major, Specify----------------------------
- ❖ How many times you have responded about the incident: (a)Never (b) Sometimes (c) Often (d) Very Often
- ❖ Have you done any improvement plans for the situation?: (a)Never (b) Sometimes (c) Often (d) Very Often
- ❖ Have you ever been taken dust control measurements at your limits: (a)Never (b) Sometime (c) Often (d) Very Often

B) If Dust Related Problem were not faced (provide the following information)

- ❖ Do you think current dust control measures are enough? (a) Yes (b) No
- ❖ If Yes, (a) Following safety code of Central Pollution Control Board (CPCB) (b) DM RC Dust Control Manual (c) Water Spraying and Soil Compaction (d) Dust Guard (e) any other specify-----

- ❖ If No, Have you prepared any improvement plan or method: (a)Never(b) Sometimes (c)Often(d)Very Often
- ❖ If so pl. specify the method: ---

4. Dust Monitoring Experience

i) Do you understand the purpose of Dust Monitoring method?: (a) Yes (b) No

ii) Have you observed the dust concentration color panels during the work?: (a) Yes (b) No

- ▪ If Yes, how often did you check in a day: (a) Rarely (b) Some times (c) Often (d) Very often

iii) Have you understand the meaning of dust color panel color provided at the work?: (a) Yes (b) No

If yes, provided meaning of each color panel and counter measures/ actions are required

(a) Blue color: Meaning -------------------- Actions-----------------
(b) Yellow Color: Meaning ---------------------Actions-----------------
(c) Red color: Meaning ---------------------Actions-----------------

iv) Do you think that the dust monitoring method is sufficient for this site? (a) Yes (b) No

If No, suggest which kind method should be considered: ---

v) Have you seen any dust problem facing during working site?: (a) Yes (b) No

vi) Do you think that problem occurred in the past could have been avoided if the site was monitored by present dust measurement method ?: (a) Yes (b) No

- ❖ If so, pl. specify how many times can be avoided---------------------------

vii) Would you like to share the Dust Monitoring information with the public (a) Yes (b)No

viii) By using dust monitoring method how much amount of severity of incident/problem (interims men and material) can be controlled?: (a)Negligible (b) Marginal (c) Significant (d) High (e) Very High

If Negligible, suggest any improvements in the present dust mobile photo monitoring method: ---------

ix) Will you recommend dust monitoring method for other /Future Metro constructions?: (a) Yes (b)No

x) Willingness to spend budget for dust monitoring and control for other /Future Metro constructions:

(a) Nominal (b) Moderate budget (c) Sufficient Budget

xi) Do you have any Ideas on "Dust Measurement and Monitoring" except present mobile phone camera method? (a) Yes (b) No

- ❖ If Yes, Suggest any method:---

xii) Do you agree this dust monitoring method will change your attitude and health conscious? (a) yes (b) No; If yes, how much dust related conscious you have improved by introducing mobile camera method? (a) No Improvement (b) Fair (c) better (d) Good

xiii) How would you rate use of dust monitoring method in construction monitoring?

(a) Fair (b) Good (c) Very Good (d) Great

xiv) Will you recommend Dust monitoring method for other /Future Metro constructions?: (a) Yes (b)No

Special Assistance for Project Implementation (SAPI) applying On Site Visualization and Dust Monitoring at Bangalore Metro construction sites

SAPI for Bangalore Metro Project utilizing Japanese ODA

Japan International Cooperation Agency

June 2011 to January 2012

SET B: Dust Monitoring Survey for Workers

Name of the Surveyor: --

Location of the Survey---Date of Survey------------Time---------------

1. Personal Details

i) Name:--- Sex: Male/Female----------

ii) Age:--------------- in years

iii) Educational Qualifications:- (a)Illiterate (b) Elementary School (c) High School (d) Intermediate (e) Others (Specify)

iv) Organization : (a) Contractor-------------   (b) Sub-contractor----------------

2. Working Experience (in years)

i) Total work experience: (a) at construction site---------- (b) other works-----------------

ii) Work experience in present organization: (a) at construction site-------------(b) other works----------

iii) Work experience at present site:-----------------(in months)

3. Awareness of Dust (No Dust Monitoring Case)

i) Do you aware about effect of dust (a) yes (b) no ; If yes do you know the impact of dust on health yes/ no

ii) Have you ever under gone dust precautionary training programme :(a) Never (b) Sometimes (c) Often

iii) How much conscious on dust do you have during working at site: (a) Poor (b) Fair (c) Good (d) Very Good

iv) Have You faced any dust allergy/ problems during working (a) yes (b) no ; If yes how often have you faced dust related problem during working at construction site?:

If so, pl. specify how many times: --

A) If you have faced any Dust related Problems (provide the following information)

Have you met any health related problems at your working site due to dust (a) Yes (b) No

If yes, provide the following Information

- ❖ What type problem (a) Breathing difficulties (b) Nose/Throat Irritation (c) Eye Irritation (d) any other specify How many times: ------------ When was the last incident/problem occurred (a) one week (b) Fortnight (c) month (d) one year (e) beyond one year -------------------
- ❖ How you responded about the problem: (a) informed to team/officers(b) Taken your own precautions
- ❖ Have you planed to avoid to work during high dust situation due to reduction in visibility (a)Never(b) some times (c) Often (d) Very Often
- ❖ Have you ever suggested to your co-worker to take precautions during working in Dust?: (a)Never (b) Sometimes(c) Often (d) Very Often

B) If you were not faced/seen any problem, provide the following Information

- ❖ Do you think current dust related safety measures are enough?: (a) Yes (b) No
- ❖ If Yes, How you satisfied with current dust related measures (no Dust Monitoring)?:

  (a) Fair (b) Good (c) Very Good
- ❖ If No, Have you prepared any precautionary method to work during construction?:

  (a)Never (b) Sometimes(c) Often (d) Very Often
- ❖ If so, pl. specify the method: --------------------------------

4. Dust Monitoring Experience (by Mobile Phone camera)

i) Do you understand the purpose of dust monitoring method?: (a) Yes (b) No

ii) Have you observed the dust concentration color panels?: (a) Yes (b) No

- If Yes, how often did you check in a day: (a) Rarely (b) Some times (c) Often (d) Very often

iii) Have you understand the meaning of dust color panel color provided at the work?: (a) Yes (b) No

If yes, provided meaning of each color panel and counter measures/ actions are required

(a) Blue color: Meaning ------------------- Actions-----------------

(b) Yellow Color: Meaning ---------------------Actions-----------------

(c) Red color: Meaning ---------------------Actions-----------------

iv)Do you think that the present dust monitoring method is sufficient for this site? (a) Yes (b) No

If No, suggest which kind method should be considered: --

v) Have you seen any dust problem facing during working site?: (a) Yes (b) No

vi) Do you think that problem occurred in the past could have been avoided if the site was monitored and controlled by dust measurement method ?: (a) Yes (b) No

- If so, pl. specify how many times can be avoided---------------------------

vii) Do you agree this dust monitoring method will change your attitude and health conscious? (a) Yes (b) No

If agree , how much rate of improvement in health conscious by introducing Dust Monitoring Method?

(a) No Improvement (b) Fair (c) better (d) Good

viii) How would you rate use of Dust Monitoring in construction safety monitoring?

(a) Fair (b) Good (c) Very Good (d) Great

ix)Will you recommend dust monitoring method for other /Future Metro or Road constructions?: (a) Yes (b)No

Special Assistance for Project Implementation (SAPI) applying On Site Visualization and Dust Monitoring at Bangalore Metro construction sites

SAPI for Bangalore Metro Project utilizing Japanese ODA

Japan International Cooperation Agency

June 2011 to January 2012

SET C: Dust Monitoring Survey for Road User

Name of the Surveyor:---

Location of the Survey:--------------------------------------Date of Survey:-------------Time:----------

1. Personal Details

i) Name:-- Sex: Male/Female

ii) Age:------- in years

iii) Educational Qualifications:- (a) Elementary School (b) High School (c) Graduate (d) Master (e) Others (Specify)-------------------------

iv) Nature of Job :- (a) Self Employ as Labor/ trader/Professional (b) Public Service(c) Private Service (d) Others(Specify)--

v) Organization Name:---

vi) Total working experience(in years):-----------------------

2. Dust Awareness

i) Are you residents/road user near to the construction site?: (a) Yes (b) No

ii) Do you aware about effect of dust (a) yes (b) no ; If yes do you know the impact of dust on health yes/ no

iii) Have you ever seen the dust related health problems due to metro construction?: (a) Yes (b)No

iv) Have you ever worried about your health and safety while passing near Metro Construction: (a) Rarely

(b) Some times (c) Often (d) Very Often

v) How much health conscious do you have: (a) Poor (b) Fair (c) Good (d) Very Good

3. **Dust Monitoring (by Mobile Phone Camera)**

i) Are You aware of the dust monitoring at the construction site?: (a) Yes (b) No

- If Yes, have you enquired about it?: (a) Yes (b) No
- If Yes, have understand the meaning of color panel?: (a) Rarely (b) Some times (c) Often(d) Very Often

ii) Have you understand the meaning of each color panel (a) Yes (b) No

iii) Have you understand the meaning of dust color panel color provided at the work?: (a) Yes (b) No

If yes, provided meaning of each color panel and counter measures/ actions are required

(a) Blue color: Meaning ------------------- Actions----------------
(b) Yellow Color: Meaning --------------------Actions----------------
(c) Red color: Meaning --------------------Actions----------------

iv) Do You think the dust monitoring by mobile phone camera is beneficial?: (a) Yes (b) No

If No, suggest any improvement method: -------------------------------------

v) Do you have any further ideas to know the dust measurement condition except using mobile phone?

(a)No Idea(b) Color Panel at entrance (c) Dash Boar Messages (a) Audio messages (b) other Specify:--

vi) Do you want to know any other information related to : (a) construction (b) Dust control measures

(c)Others

vii) Do you agree this dust monitoring method will change your attitude and health conscious?

(a) yes (b) No; If yes, how much dust related conscious you have improved by introducing mobile

camera method? (a) No Improvement (b) Fair (c) better (d) Good

viii) How would you rate use of dust monitoring method in construction monitoring?

(a) Fair (b) Good (c) Very Good (d) Great

ix) Will you recommend Dust monitoring method for other /Future Metro constructions?: (a) Yes (b)No

AUTHOR’S PUBLISHED PAPERS

Author's Published Paper - 1

Title : Measuring and monitoring construction dust using mobile phone cameras, CURRENT SCIENCE, Vol.104, No.7, pp.817-821, 10 April, 2013.

Author's Published Paper - 2

Title : Dust Monitoring System by Network Camera on Video Processing, Journal of Japan Society of Civil Engineers, Ser.F1(Tunnel Engineering) Vol.70, No.1, pp.15-25, 2014.

Measuring and monitoring construction dust using mobile phone cameras

Dust is a generic term used to describe fine particles that are suspended in the atmosphere. Sources of dust emitted directly into the air are due to vegetation, burning of biomass, industrial and construction of activities, wind-blown, etc. Dust can be defined in practical terms as any particle from a few nanometres (nm) to a few micrometres (μm) in diameter that can become suspended in the atmosphere. According to the British Standard code (BS 6069-2)[1] dust is defined as a solid particulate matter (PM) 1–75 μm in diameter. Dust can be formed due to particles which are emitted directly and secondary particles which are formed by chemical processes in atmosphere. Particle size is an important factor influencing the dispersion and transport of dust in the atmosphere and its effects on human health. Particles less than 10 μm in diameter (known as PM_{10}) are often inhalable, while particles less than 2.5 μm are considered respirable (known as $PM_{2.5}$). Particle size less than 10 μm can cause health hazards, whereas those greater than 10 μm are associated with public perception and nuisance[2]. PM10 is of more concern to human health as the particles can enter the lungs, causing breathing and respiratory problems, with long-term health effects. These particles also carry adhered carcinogenic compounds into the lungs[3].

Construction dust consists of direct particulate matter which is emitted due to construction work on ground, and poses a great problem for health and environment. In India, there is a regulation that dust concentration during construction must be less than 2.5 mg/m^3 (Central Pollution Control Board (CPCB)). However, dust measuring, monitoring and counter measures have not been properly implemented so far because dust measurements are expensive. In India, the construction industry is the second largest employer next to agriculture; it employs around 10 million people. The annual turnover of the construction industry is more than 6% of the national GDP. It is one of the most vulnerable segments in terms of safety and health-related incidents in comparison with the other sectors. Several research and engineering techniques have been developed to provide dust-monitoring measures at construction sites. Recently, in construction sites in Japan, digital camera-based methods for measuring dust were introduced. Further, these methods are improved by introducing innovative techniques using mobile phone cameras, because the performance of these cameras has improved significantly. Shinji[4] initially developed an innovative, handy and quick dust-monitoring method using a mobile phone camera to measure the dust concentration at a construction site. This new method is more economical, easy to perform and also has a high correlation with digital dust indicator (DDI).

The objective of this study is to investigate the implementation of mobile phone camera-based dust-measuring technique to plan and execute the dust-management system at a construction site. The developed methodology is implemented for monitoring at Central College metro station in Bangalore. This method is quite useful to the workers at the construction site to take precautions based on the level of dust concentration. The mobile monitoring system was calibrated and validated against the traditional DDI method to assure statistical validity. The result of this measurement was also displayed on a colour panel at the construction site so that workers could take required precautions accordingly.

Where particulate matter is considered to be the main ambient air pollutant, two dust fractions are commonly used in monitoring programmes, PM_{10} and $PM_{2.5}$. The PM_{10} includes particles with an aerodynamic diameter up to 10 μm and $PM_{2.5}$ represents particles with an aerodynamic diameter up to 2.5 μm. Aerodynamic diameter is defined as the diameter of a hypothetical sphere of density 1 g/cm^3 having the same terminal velocity in calm air as the particle in question, regardless of its geometric size, shape and true density[5].

Dust can be divided into four categories: generated dust, total suspended dust, nuisance dust and fugitive dust nuisance[2]. The scope of this study is measuring and monitoring of construction dust which is mainly due to generation at construction sites. To evaluate the impact of dust on human health due to exposure to dust or to investigate the effectiveness of dust control measures, one must have a method for the evaluation of dustiness. Many methods have been used in the literature to measure the dustiness at construction sites – particle mass-based methods or particle count method, particle light scattering methods and particle light absorption methods, mobility measurements and chemical components and precursor gases equipment. Particle count method was developed based on air as it enters and exits the filter. Filter efficiency is the ratio of particles trapped by the filter to the total number of particles found in the air upstream of the filter. Mass concentration method is the simplest among the dust-measuring methods to determine the total weight of dust collected in a given volume of air. In gravimetric method air passes through the instrument at a desirable rate of 2.5 l/min under the action of a diaphragm pump. The major advantage of modern light scattering instruments is that the addition of electronic circuitry permits a combination of immediate readout and integration over any chosen time-interval. Hence, they can be employed for both short-term and long-term sampling.

In recent years, because of the performance improvement of mobile phone cameras, they were used to measure the concentration of dust at various constructions sites[4]. This method is easy to handle and inexpensive in long run. The flash photograph taken by the camera is used for the internal processing to quantify the dust density. With the help of artificial neural network (ANN) techniques, the flash photographs can be processed and the most probable dust density can be estimated. For this entire internal processing in the mobile phone, Shinji[4] developed the dust concentration measuring program on a HTC desire Android OS 2.2 version and this was installed in the hand phone. Figure 1 represents the dust measuring mechanism using the mobile phone camera. ANN has been adopted in this study to measure the dust concentration. A neural network consists of a number of inter-connected processing units, commonly referred to as neurons or neurodes. Each of these neurodes receives input signal from other neurodes to which it is connected and each of these connections has numerical weights associated with it. These weights describe the nature and strength of the influence of the network and are adjusted iteratively until the error is reduced within tolerable limit. The validity of dust concentration measured by this method is compared with the traditional dust concentration measures such as DDI.

Bangalore city, the capital Karnataka, occupies an important position not only in the state but also in the country. It is considered as one of the major industrial, commercial and educational centres in southern India. Urbanization in India is more rapid around national capital and state headquarters. Bangalore is no exception to this case. It has the dubious distinction of being the fastest growing metropolis in the country. Similarly, vehicular population has been increasing tremendously, leading to traffic congestion and uncertainties in travel time. To mitigate these problems, mass transit for Bangalore had been started under the Bangalore Metro Rail Corporation Ltd (BMRC). Figure 2 shows the route map of east–west corridor of Bangalore Metro rail alignment phase 1. The red colour alignment shows the underground corridor and the blue alignment shows the elevated corridor.

For the present study, Vishveshwaraya station (Figure 2), also called the Central College station (8.78 km), in the east–west corridor of Bangalore Metro Project phase-I has been considered. In this study four locations were identified to measure dust concentration (Figure 3).

The methodology for dust measuring and monitoring at Central College station is shown in Figure 4. The entire procedure is as follows: taking flash photographs at the identified locations in the study area, calculation of dust concentration, development of database in the server provided by the Indian Institute of Science (IISc), Bangalore, and data analysis and information to the site workers through colour panel.

The traditional digital dust measuring instrument, SIBATA modelled Digital Dust Indicator LD-3K2 model equipped with a laser that measures relative concentration of respirable particles through the intensity of scattered light was used. Prior to monitoring each day, background and span checks were conducted to remove filled air in the detector, and compare the measured value of the light scattering plate. The relative concentration of Suspended Particulate Matter (SPM) with size less than 10 μm in diameter was measured every minute, and expressed as counts per minute (CPM). Dust measuring system developed by mobile camera needs calibration before collection of real data. For this, the pho-

Figure 1. Dust measuring system using mobile phone camera.

Figure 2. East–west corridor route map of Bangalore Metro.

Figure 3. Dust-monitoring at Vishveshwaraya metro station.

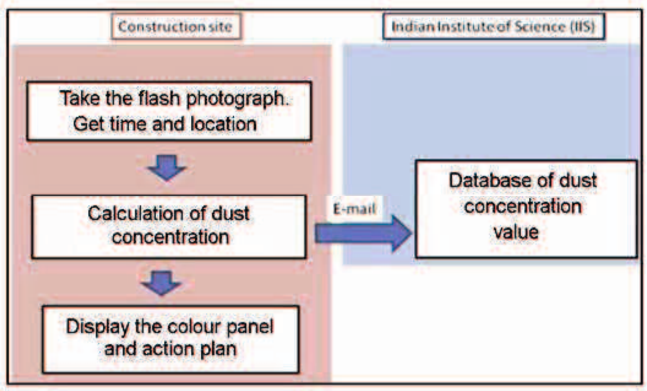


Figure 4. Methodology for dust monitoring in the study area.

tographs taken in Dust Box were synchronized with DDI and correlation analysis was carried out after calibration and validation of dust monitoring system (DMS) values.

Correlation analysis was carried out between dust concentration measured by mobile phone camera and that measured by DDI to know the degree of correlation among values obtained by both these techniques. For this, 108 samples were collected simultaneously using both techniques. The sample collection of dust concentration data is spread over various time-periods such as morning, afternoon and evening hours at four different locations of the study area represented (Figure 5). From Figure 5, it can be observed that highly positive correlation ($r = 0.94$) exists between the dust concentrations measured by both the techniques.

Further, regression analysis was carried out to understand the relation between the dust concentrations measured by these methods. The estimated regression model coefficients for the collected sample are presented in Table 1. The sign of the estimated coefficients of the variable is positive; this indicates that the dust concentration measured by the mobile phone camera showed a positive contribution to DDI value. Based on t-statistics (greater than 1.95), it can be concluded that there is significant relation among these values. The estimated R^2 values were very high (0.88), which indicates that the uncertainty explained (88%) by these values is very high. Also, observed F value is high (799.284) and significance of P value is less than 0.005. This emphasizes that the dust concentration measured using the mobile phone camera is significant. Further these values are validated on statistical grounds using standard t-test and F-test.

The dust concentration data obtained using mobile phone camera were validated against the DDI dust concentration values. Mainly these values are statistically validated by considering Student's t-test for significance of difference between the means of observed DDI values and DMS values. F-test is also considered for validating the significant difference in variance of observed dust values obtained by both instruments.

The t-statistic value is estimated using eq. (1) to assess the statistical validity of mean between the dust measured by mobile phone (DMS) and DDI.

$$t = \frac{x_a - x_m}{\sqrt{\frac{s_a}{N_a} + \frac{s_m}{N_m}}}, \quad (1)$$

where x_a and x_m are the mean values of dust concentration measured by mobile phone camera and DDI respectively, s_a and s_m are the values of variance of DMS and DDI dust concentration measured respectively, and N_a and N_m are the sample size of DMS and DDI values respectively. It can be observed from Table 2 that the t-value obtained by eq. (1) is less than the t-critical value for 5% level of significance, which is obtained from the standard t-table. This emphasizes that the dust values measured by mobile phone values have no significant difference with dust measured values by DDI.

After validation, DMS is used in the present cut and cover metro construction site. The developed DMS was difficult to use directly under sunshine, to overcome this difficulty, a dust-monitoring chassis box was developed to measure dust concentration. The box is kept open to collect the dust concentration before taking the measurement. Then the box is closed and the flash photograph taken in the dark box.

For the present study, data were collected in three locations (Figure 3). A total of 48 days dust data have been measured in September, October and November 2011. Dust was measured during four different time periods on each day, i.e. at 9.00 a.m., 11.00 a.m., 2.00 p.m. and 5.00 p.m. and four dust samples were collected each time. The average concentration for each time-period was estimated for each sample for each location. This was considered in the analysis and decision-making for an action plan. The sample size collected for various locations is presented in Table 3.

The dust concentration data measured at all the three locations were analysed and summary of statistical parameters such as mean, median, kurtosis, skewness for all the locations were estimated (Table 3). This statistical information of dust concentration is useful to know about the central tendency and variability of dust concentration at the measured locations of the study area during work. Table 3 shows that the mean of dust concentration at location 3 is marginally higher than that in the other locations. The standard deviation for this location is also higher (1.78 mg/m^3). The kurtosis value provides a measure of the 'peakedness' of dust concentration. Location 1 has a higher kurtosis value indicating high peak values and less variability than the other locations. It can be observed from the results that the width of the particle size distribution of location 3 is more than those at locations 1 and 2. Dust collected over the entire sampling interval was low, but when dust concentration was expressed in terms of drilling time,

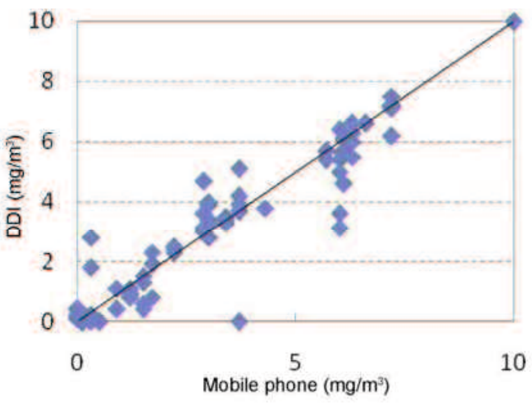


Figure 5. Correlation of dust concentration using mobile phone camera and digital dust indicator (DDI).

Table 1. Coefficients estimated by linear regression analysis

	Coefficients	Standard error	t Stat	P value
Intercept	0.118	0.148	0.797	0.427
DMS (mg/m^3)	0.945	0.033	28.272	0.000

Table 2. Statistical summary of validation results of measuring dust

Dust values measured by mobile phone camera		Dust measured by digital dust indicator		Student's *t*-test	
Average	Variance	Average	Variance	*t*-value	*t*-critical
3.370	8.418	3.304	8.530	0.168	1.990

Table 3. Statistical summary of the dust concentration measured in the study area

Statistical parameter	Location 1 (sample size 120)	Location 2 (sample size 83)	Location 3 (sample size 118)	Combined (sample size 321)
Mean	1.84	1.91	2.05	1.97
Median	1.33	1.36	1.56	1.36
Standard deviation	1.63	1.62	1.78	1.75
Kurtosis	7.83	7.08	5.55	5.60
Skewness	2.14	2.09	2.03	2.01
90th percentile of dust concentration	3.40	4.0	4.20	4.20

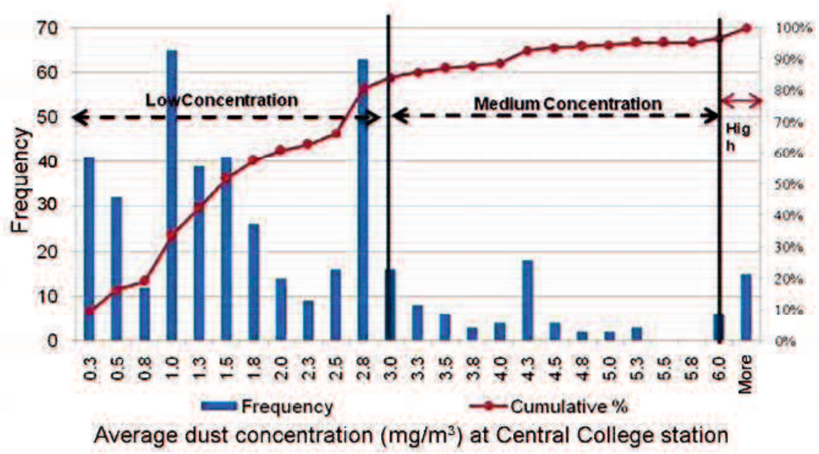


Figure 6. Combined average particle size distribution of samples collected at locations 1–3.

dust exposure increased. Further to discuss this scenario additional and repeated measure of dust concentration is necessary. Based on the observations, it is therefore recommended that the workers should wear filtered dust mask during drilling at the locations.

The probability of particle size distribution of dust concentration of the combined data is presented in Figure 6. It can be observed that all the distributions are skewed to the right. From the cumulative distribution it was observed that the median value (at 50%) is almost the same in all the locations and is about 1.4 mg/m^3, except at location 3 where it is about 1.60 mg/m^3. The 90th percentile of dust concentration levels has crossed the lower safety limit which is 3.0 mg/m^3. That is out of 20 measured samples two samples cross the lower concentration level in all the three locations. Therefore, from the observed results it is strongly suggested that the workers should use at least a simple dust mask while working at any location.

In this study a method has been introduced to measure dust concentration using a mobile phone camera. The method is dynamic and a good alternative to traditional methods such as DDI. This innovative technique has been calibrated and validated before implementation in the study area. For this, the traditional DDI data were considered. From the results of calibration it has been identified that high positive correlation ($r = 0.940$) exists between the dust concentrations measured by DDI and mobile phone camera. Further, the data were validated statistically by using *t*-test. The results show that there is 5% level of significance in the dust concentration measured using mobile phone camera.

Further this method was implemented at the construction site of Central College station, Bangalore Metro and a total of 445 samples were collected from four different locations in the study area. It was observed from particle size distribution of dust concentration that the median value is almost the same in all the measured locations at Central College metro station (1.5 mg/m^3). The 90th percentile of dust concentration levels crossed lower safety limit of 3.0 mg/m^3, i.e. out of 20 measured samples, two samples crossed the lower concentration level in all the measured locations. Based on the observed results, it is strongly suggested that simple dust masks need to be used as a preventive measure in construction work. If the concentration level crosses the upper safety limit of 6.0 mg/m^3, simple mask protection might not help reduce exposure sufficiently. The combined use of dust masks with filters can reduce exposures to acceptable levels.

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REIKO ABE[1]
CH. RAVI SEKHAR[2,*]
S. SASAKI[3]
K. R. SHIVANANDA[4]
M. SHINJI[3]

[1]*Oriental Consultant Ltd, Tokyo, Japan*
[2]*CSIR-Central Road Research Institute, New Delhi 110 025, India*
[3]*Department of Civil Engineering, Yamaguchi University, Japan*
[4]*Planning, Procurement & Controls, Bangalore Metro Rail Corporation, Shanthi Nagar, Bangalore 560 027, India*
**For correspondence.*
e-mail: chalumuri.ravisekhar@gmail.com

Eastern Ghats' biodiversity reserves with unexplored lichen wealth

The Eastern Ghats (EG) is a discontinuous range of mountain situated along eastern coast of India (Figure 1). It stretches from Mahanadi Basin in the north to Nilgiri Hills in the south, covering a distance of 1700 km and spreading over an area of 75,000 sq. km. The average elevation of the mountain range is about 600 m and the highest peak is Shevaroy Hills that reaches up to a height of 1700 m. EG supports a rich array of tropical forests including pockets of moist deciduous, evergreen and semi-evergreen forests. About 2600 angiosperms, gymnosperms, pteridophytes and 160 cultivated plants are known from EG[1], which also includes over 530 tree species, 1800 medicinal and 450 endemic plants[2]. The biodiversity richness in the region can be illustrated with an example from six hill complexes of the southern EG wherein 143 lianas and 272 tree species are reported[3,4]. The EG is home to several unique taxa such as *Shorea roxburghii* G. Don (*S. talura* Roxb.), *S. tumbaggaia* Roxb., *Pterocarpus santalinus* L. f. (red sanders), *Cycas beddomei* Dyer and some wild varieties of rice (*Oryza granulata* Nees & Arn., *O. sativa* Thw. and *O. malampuzhaensis* Krish. & Chand.)[5,6]. EG is also a region for discoveries of taxonomic novelties; for example *Corallodiscus* Batalin, a new generic record of plant and *Phallus indusiatus* Vent. & Pers., a new generic record under fungus are reported from Odisha[7,8]; *Clarkeinda trachodes* (Berk.) Singer, a rare tropical Asian monotypic mushroom was recorded from Tamil Nadu (TN)[9]. Apart from plants, Rao and Krishna[10] recently discovered two species of spider and one each species of scorpion and mantis from the Nallamala Hills.

EG contributes significantly to both species richness and endemicity of the Indian region. However, the forests of EG are relatively under-studied and have received less attention for conservation compared to the relatively better-known Western Ghats[3,11]. Ultimately EG is left with insufficient data for several groups of organisms. This is one of the reasons that phytogeographers were forced to merge EG with the Deccan Plateau and call it the Deccan peninsular biogeographic zone[12]. The data deficiency is prominent in the case of cryptogams, especially lichens. Singh and Sinha[13]

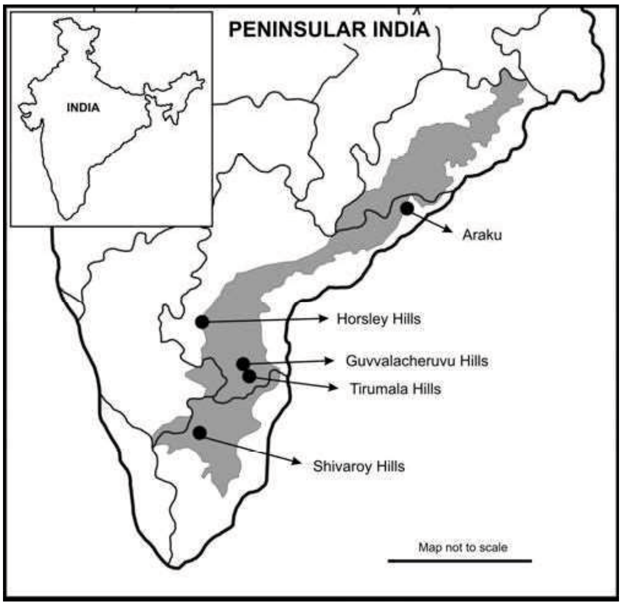

Figure 1. Schematic presentation of Eastern Ghats and some important localities surveyed for lichen collection in the present study.

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動画像処理理に基づくネットワークカメラによる簡易粉じん濃度測定法

阿部　玲子[1]・佐々木　雄紀[2]・進士　正人[3]

[1](株)オリエンタルコンサルタンツ　GC事業本部　軌道交通部（〒151-0071 東京都渋谷区本町3-12-1）
E-mail: aber@oriconsul.com

[2]正会員　鹿島建設(株)　海外土木支店（〒107-8348 東京都港区赤坂6-5-11）
E-mail: yukis@kajima.com

[3]正会員　山口大学教授　大学院理工学研究科（〒755-8611 山口県宇部市常盤台2-16-1）
E-mail: shinji@yamaguchi-u.ac.jp

スマートフォンを用いたトンネル坑内簡易粉じん濃度測定法を，インドの開削現場での明環境下で適用したところいくつかの問題点が生じた．本論文では，近年トンネル切羽作業監視用として急速に普及しつつあるネットワークカメラを用いて，従来のスマートフォンによる写真撮影では問題となった背景の影響を動画の時間差分処理により除去するとともに，二値化処理，モルフォロジー処理および領域分割などの画像処理により，高精度な粉じん粒子抽出を実現した．そして，粉じん濃度の特徴量として画面内における粉じん散乱光部分の面積と個数を新たに採用することで，従来法より安定した粉じん濃度測定法を確立した．室内実験の結果，提案手法は従来法と比べて粉じん部分の抽出性能だけでなく，十分な精度も合わせて有していることを確認した．

Key Words : *dust monitoring, video image processing, feature value, smartphone, network camera*

1.　はじめに

トンネル建設現場で発生する浮遊粉じんは作業員の肺機能障害を引き起こす原因物質のひとつとされており，国内では1980年代以降，数多くのじん肺訴訟が提起され，国の責任が問われてきた．そのため，厚生労働省は，2007年12月に粉じん障害防止規則を改正し，電動ファン付き呼吸用保護具の着用と，デジタル粉じん計を用いた定期的な粉じん測定を管理者に義務付けた[1]．

一方，海外外での社会資本への投資活動は極めて活発であり，特に発展途上国での建設需要は非常に大きい．しかしながら，発展途上国においてトンネル建設に従事する労働者の健康意識は日本に比べまだまだ低く，このまま放置するとわが国と同様のじん肺訴訟問題に発展する可能性が極めて高い．そのため，早い段階からの建設作業員の健康意識改革と粉じん濃度測定の一般化が重要である．現在，粉じん濃度測定に広く用いられているデジタル粉じん計は，一般的な計測機器として，わが国ではレンタルも可能で利用が容易であるが，海外ではきわめて高価な計測機器である．加えて，計測結果をリアルタイムで周知できないなどの問題があった．

そこで，著者らは既往研究[2]においてこれらの問題を解決する簡易な測定法として，デジタルカメラのフラッシュ光による粉じん散乱画像を利用した簡易粉じん濃度測定法を提案した．中でもスマートフォンによる方法はデジタル粉じん計に比べ安価で簡易な測定方法として，**写真-1**に示すインドのバンガロール地下鉄工事における駅舎部岩盤開削工事現場において試験適用された[3]．適用現場がトンネル坑内ではなく開削工事である中で，暗環境下の粉じんの光散乱画像を得るためのアルミニウム合金

写真-1　インド地下鉄駅開削工事現場

製粉じん計測箱（以下,「ダストボックス」と呼称する.）を考案し，現場適用を行った．しかし，ダストボックスを用いる方法には測定精度の長期維持に問題を有し，計測環境の変化に合わせた頻繁なキャリブレーション（学習）が必要となることがわかった.

本研究では，スマートフォンを用いた簡易粉じん濃度測定法の原理について簡単に述べたうえで，開削現場でこの測定法を適用した際の問題点を明らかにする．そして，その解決方法として，動画像を用いた簡易粉じん濃度測定法を提案し，その手法をネットワークカメラを採用した場合の適用結果について示す.

2. スマートフォンを用いた簡易粉じん濃度測定法

(1) 基本原理

まず，既往研究で提案された簡易粉じん濃度測定法の原理についてその概略を述べる.

図-1(a)に示すような暗環境下で，粉じんが浮遊している空間に対してデジタルカメラでフラッシュ撮影を行うと, **図-1(b)**に示すような光散乱画像が得られる. これは, カメラのフラッシュ光が 0.5μm 付近の波長域にピークを持つため，粒子の粒径が入射光の波長と同程度以上の大きさの粒子により起こるミー散乱により数 μm 程度の浮遊粉じんの散乱光がカメラに写ると考えられている [4]. その際の散乱光強度は，光学系と粒径が一定であれば粉じん個数に比例する．既往研究では，この性質を利用し，つや消し黒色スプレーで塗装したパネル（以下,“ブラックパネル”と呼称する.）に対してカメラでフラッシュ撮影された浮遊粉じんの光散乱画像輝度の平均値，分散値を特徴量としてパソコン上でニューラルネットワーク（Artificial Neural Network, 以下‘ANN’と呼ぶ.）を用いた学習を行うことで粉じん濃度の変化に対応する測定法を確立した．ANN とは，人間の刺激と反応に関する脳神経組織を数学的に模擬したコンピュータアルゴリズムである [5]. この方法では，写真撮影はデジタルカメラ，粉じん濃度測定はパソコンとそれぞれの機器を組み合わせて使用しなければならず，即時対応の点で難点があった. そこで，単体としての性能は落ちるものの写真撮影機能と演算機能を有しているスマートフォンのフラッシュ付きカメラにより同様のフラッシュ撮影を行い，撮影画像をスマートフォン上の AndroidOS 上で解析することで, リアルタイムに粉じん濃度が得られるシステム（Dust Monitoring System by Smartphone, 以下“DMS-S”と呼ぶ.）を開発した．DMS-S は，デジタル粉じん計に比べ，きわめて簡易かつ安価であったため，海外建設工事における適用が検討された.

(2) 開削工事現場への適用

海外での適用現場として，インド・バンガロール地下鉄駅建設のための開削工事現場が選定された．インドでは，建設作業中の許容粉じん量の規制が不明確であるうえに，粉じん測定器が非常に高価であることもあり，定常的な粉じん測定は行われていない．そこで，まず粉じん濃度測定の事前調査として発生粉じんの粒度試験を行った [3),6)]. **図-3** に調査の結果得られた浮遊粉じんの粒度

(a) フラッシュ無し

(b) フラッシュ有り

図-1 トンネル坑内での撮影画像比較

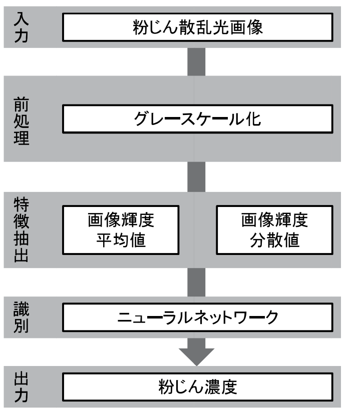


図-2 DMS 測定手順

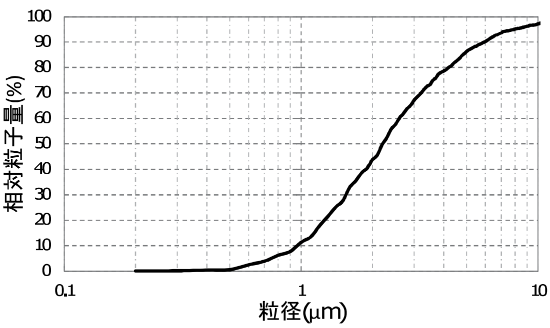


図-3 発生粉じんの粒径分布曲線

分布を示す．図からわかるように，浮遊粉じんはPM2.5をほぼ平均粒径として，フラッシュ撮影により観測可能な0.5μm～2μmの粉じんが全体個数の約40%程度含んでいる．そこで，国際協力機構のインド，バンガロール地下鉄建設プロジェクトへの支援の一環として，試験的な簡易粉じん濃度測定の適用を6ヶ月間にわたり行った．

適用現場は地下鉄駅建設のための開削工事現場であったため，従来のままではフラッシュ散乱光の取得が困難であった．そこで，可能な限りのフラッシュ散乱光の安定的な取得と開削作業現場内での持ち運びを勘案し，試行錯誤の結果，**写真-2**および**図-4**に示すダストボックスを開発した．ダストボックスの寸法はL760×W450×H470（mm），重さは6.1（kg）である．ダストボックスの内部はつや消し黒色スプレーで塗装した上に，撮影領域には前述のブラックパネルを設置した．側面にはスマートフォンより一回り小さい穴を開け，スマートフォンをゴムバンドで外から固定することで，上蓋を閉じた状態でもスマートフォンを外側から操作できるようにした．このダストボックスにより，測定直前に上部の蓋を閉め，日光を遮断することで，トンネル坑内と同様の粉じんの光散乱画像の取得が可能となった．

適用現場は開削工事現場であったため，開削作業の工程を勘案し，工事現場内の5か所に計測点を設置し，その間，ダストボックスを運搬しながら，一日に4回（9時，11時，14時，17時）計測した．計測は，ダストボックス側面にスマートフォンを固定し，ダストボックス上蓋を開放し周囲の粉じん濃度と同調させ，その直後に，上蓋を閉めスマートフォンでフラッシュ撮影を行い実施した．各測定点での測定は各地点でそれぞれ5回実施し，最高，最低の粉じん濃度を除いた残り3回の測定結果の平均値をその箇所の粉じん濃度とした．

(3) 発生した問題点

開削工事現場での具体的な計測位置，計測結果については参考文献3)に示したとおりである．その中で，DMS-Sの適用の問題点は大きく分けて2つあった．1つはDMS-Sが時おり高濃度を表示するはずれ値問題であり，もう1つはDMS-Sがある時点から一定値のみを示す一定値問題である．どちらも測定精度を下げる要因であり，開削現場に適用するために用いたダストボックスに関連し発生した問題である．特に2番目に挙げた一定値問題に直面すると学習を一からやり直さなければならず，適用現場にスマートフォンが1台しか存在しない場合，学習の手間はもちろんのこと，その現場での粉じん測定が滞るなどの障害が発生する．以下，それぞれの問題の詳細および推定原因を述べる．

a) はずれ値問題

図-5に，開削工事現場における同一計測地点における，ある一日のデジタル粉じん計およびDMS-Sによる粉じん濃度測定の比較結果を示す．1回目，2回目，3回目の測定では同様の傾向を示しているのに対し，4回目の測定ではDMS-Sが10.0mg/m^{3}と，デジタル粉じん計の測定結果に比べ極端に高い値を示した．この時のフラッシュ撮影画像には，**図-6**に示すように画面左上に大きな白斑が写っていた．これはカメラのレンズ極近傍に浮遊粉じんが浮遊し，その粉じんからのフラッシュ散乱光が他の粉じんに比べ，極端に大きく明るく写ったものと考えられ

(a) 外観　　(b) カメラ設置部

写真-2 ダストボックスとカメラと設置状況

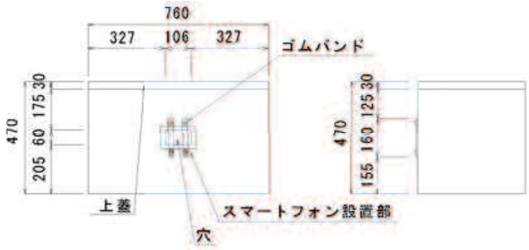


図-4 ダストボックスの寸法図

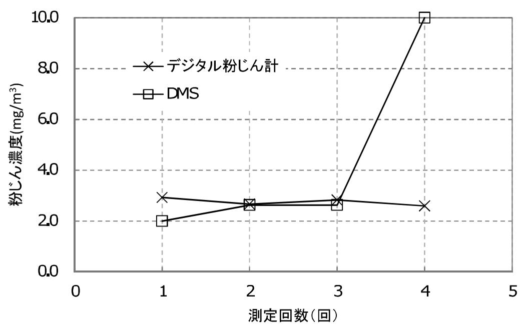


図-5 デジタル粉じん計とDMS-S測定結果比較

図-6 大きな白斑の写った画像例

る．写っているのは 1 個の粉じんであり，デジタル粉じん計による測定粉じん濃度は低い，しかし，この画像の輝度値は見かけ上非常に高いため，DMS-S では高粉じん濃度と誤って評価してしまうことがわかった．このように，高粉じん濃度が得られた場合には写真を確認し，**図-6** のような画像が撮影された場合に対しては，計測をやり直すことにより対処したが，粉じん濃度の自動測定のためには工夫が必要であることがわかった．

b) 一定値問題

図-7 に DMS-S による粉じん濃度測定結果の一例を示す．この例では 125 回までの測定は問題なく行えたのに対し，126 回目以降では 1.2mg/m^3 という一定値のみを示し，測定環境の変化が疑われた．点検の結果，スマートフォン自体に異常はみられず，デジタル粉じん計も正常に動作していたため測定自体が極端に変化した可能性は低い．そこで，フラッシュ撮影時の背景であるブラックパネルの黒色度の経時変化に着目し，室内再現実験を実施した．室内再現実験は，暗環境下とし，上蓋を開放したダストボックス内にデジタル粉じん計，デジタルカメラを設置し，現場で採取した切削粉じんをダストボックス上部から内部に向かってふりまくことで低から高粉じん濃度状態を再現した．

c) 発生原因

背景の黒色度の経時変化が DMS-S へ与える影響の確認を目的に，3 種類の異なる表面を持つブラックパネルを準備し，それぞれのパネルに対しフラッシュ撮影を行った．そして，フラッシュ写真毎に，ANN で用いる特徴量である光散乱画像の平均値と分散値を求めた．**図-8** に，その平均値，分散値と，デジタル粉じん計を用いて測定した撮影時の粉じん濃度との相関図を示す．図中，ブラックパネル 1 は塗装直後の状態，ブラックパネル 2 はブラックパネル 1 の表面に意図的に粉じんを付着させた状態，ブラックパネル 3 はブラックパネル 2 を清掃した状態である．この図からわかるように，画像輝度の平均値や分散値は，どのパネルでも粉じん濃度との相関は弱く，ブラックパネルの背景条件の変化に強く影響を受けていることがわかる．すなわち，ブラックボックス内ではスマートフォンとブラックボードの距離が近いので，従来の DMS-S で用いていた特徴量は，背景の変化に敏感で，高頻度の清掃を必要とするため長期運用には適さないことが明らかとなった．

図-9 に，DMS-S で用いる ANN の模式図を示す．ANN のアルゴリズムは，入力した多数の刺激（特徴量）による反応を経験として自動的に学習し，定式化やモデル化が困難な事象の判別解析に適しているため，DMS-S に適用された．既往研究において，ANN の層数およびニューロン数は経験的に決定されており，その設定方法は特定の事前検討データを用いて行われていた．そのため，パネル毎に ANN による広範囲の学習を行わなければ，安定的な粉じん濃度測定ができず，**図-7** のようにある一定値のみを出力することになると判断した．

従って，開削トンネルを適用対象として，ダストボックスを利用する簡易粉じん測定の場合，DMS-S に対する ANN の適用にはその検討が不十分であり，特徴量と識別アルゴリズムを再度検討することにした．

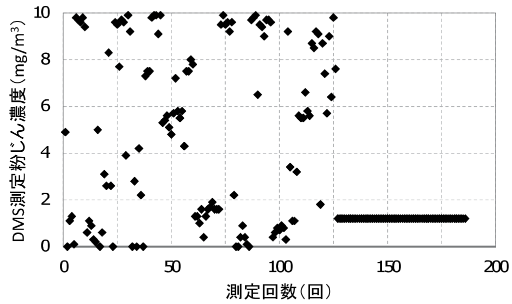
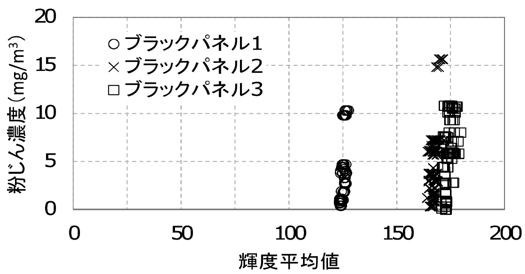
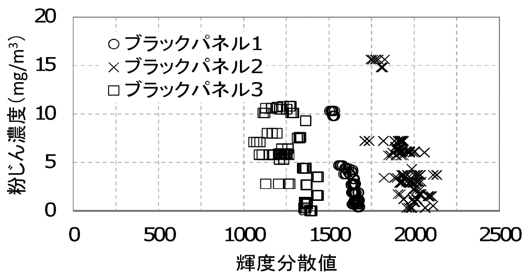


図-7 DMS-S 測定結果による一定値問題の発生例



(1) 輝度平均値



(2) 輝度平均値

図-8 特徴量と粉じん濃度との相関図

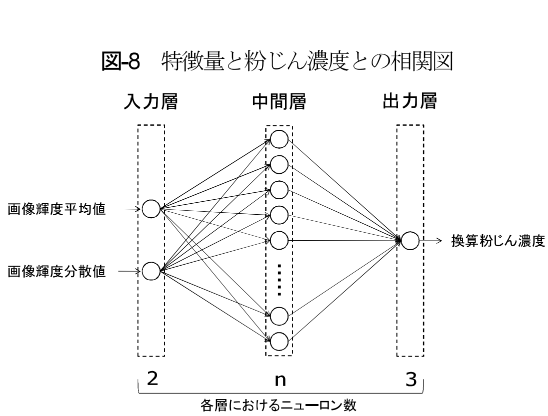


図-9 DMS-S で用いた ANN 模式図

3. 動画像処理による粉じん濃度測定法の検討

(1) 動画像

ビデオ画像のような動画像は，一般に，直行する2次元の x, y 空間座標と，1次元の時間座標 t で表現される3次元的な広がりを持ったデータ集合群と考えられる．ここで，白黒の動画像は輝度（濃度）情報のみをもち，次式のように表される[7]．

$$\text{動画像} = f(x, y, t) \tag{1}$$

それに対し，カラー画像では，各画素に対してR（赤），G（緑），B（青）の3色の濃淡情報が必要となり，取り扱う情報量は単純に3倍となる．時間に関しては1秒間30画像が標準である．

簡易粉じん濃度測定に動画像を利用する利点として，写真（静止画）には無い時間 t を取り扱うことができる点が挙げられる．具体的には，連続するフレーム間での差分処理（時間差分処理）を行い，長期運用で問題となった背景変化の影響の低減に関する検討を行う．

(2) 動画像における連続散乱光画像取得方法

動画像上での抽出対象物の分解能は，画像取得時の撮影機器と抽出対象物である粉じんおよびその背景であるブラックパネルとの距離や光学レンズの性能，画像の解像度，フラッシュライトの光量・位置などによって変動する．これまでの研究により，安定した光散乱動画像を取得するため，フラッシュ光の代替光源としてLEDライトを散乱光源とし，スマートフォンのビデオ撮影で粉じんの散乱光動画像が撮影できることはわかっていた[8]．そこで，画像処理手法の確立に当たっては，まずスマートフォンのビデオ撮影機能を用いた．そして，トンネル坑内での定点観測としての粉じん測定を目的としてトンネル切羽付近の作業状況の撮影に用いられているネットワークカメラと，LEDライトを組み合わせることとした．

(3) 時間差分処理

時間差分処理とは，**図-10** に示すように異なる時刻の連続した2枚の画像を差分し，画像中で輝度差が発生した部分を抽出する処理である．すなわち，観測画像を $f(x,y,t)$ とすると，時間差分画像 $\Delta d(x,y,t)$ は，以下のように示される．

$$\Delta d(x, y, t) = \left| f(x, y, t) - f(x, y, t-1) \right| \tag{2}$$

ここで，x は画像水平方向のピクセル，y は画像垂直方向のピクセル，t は画像番号である．

同図に示すように，粉じん散乱光動画像において(2)の差分処理を行った場合，輝度差が発生する部分は粉じん散乱光部分のみになるため，従来問題であった背景部分の影響を除去する，すなわち粉じん散乱光のみを抽出することができる．

実際に粉じん散乱光動画像を用いて時間差分処理を行った結果の一例を**図-11(b)**に示す．なお，時間差分処理で比較する画像は，粉塵が重ならない時間間隔として0.1秒とした．これらの図においてデジタル粉じん計で計測された粉じん濃度は8.9mg/m^{3}である．これらの図から明らかなように，時間差分処理により画像中央部の反射光の影響を除去できていることがわかる．しかし，差分により画像全体が暗くなり，粉じん散乱光部分も同様に認識し難くなった．また，入力値である元画像は，光学変換部や増幅器のノイズや光学系のひずみなどの影響（以下これらを“ノイズ”と総称する）を受けており特徴把握は依然として困難であった．そこで，次に示す画像補正を行った．

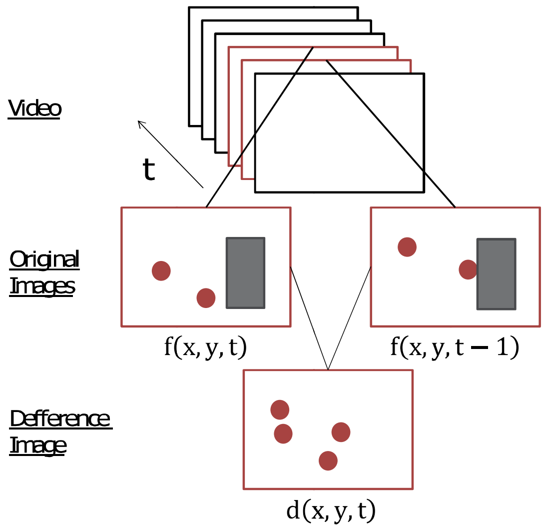


図-10 時間差分処理のアルゴリズム

図-11 時間差分処理適用結果の一例

図-12 グレースケール画像

(4) 画像補正

図-11(b)には，各画素がRGB（赤r_{ij}，緑g_{ij}，青b_{ij}）という 3 つの値であらわされている．以降の処理が煩雑となるのを防ぐため，各画素のRGB値を次式から最小値0を黒，最大値255を白とした256階調のグレースケール画像に変換し，$n \times m$ 行列 a_{ij} を作成する．ここで，$n \times m$ は画像のサイズである．

$$a_{ij} = 0.2989 \times r_{ij} + 0.5870 \times g_{ij} + 0.1140 \times b_{ij} \tag{3}$$

図-11(b)をグレースケール画像に変換した結果を**図-12**に示す.

a) 二値化処理

図-12の画素数を縦軸, 輝度値を横軸にした画像輝度値のヒストグラムを**図-13**に示す. この図からわかるように, ほとんどの画素の輝度値は25以下となる．このため画像全体が暗くなり，目的の粉じん部分の特徴把握そのものも難しくなったと考えられる.

そこで二値化処理を適用した．二値化処理とは連続階調で表された画像を白，黒の二値に変換する処理である．その際，しきい値を設けその値以上の階調は白，それ以下は黒に変換する．二値化処理を適用する利点として，対象物と背景を簡便に切り離すことができる．本研究においては，粉じん散乱画像が対象物，ブラックパネルが背景にあたるため，画像からの特徴抽出が容易となるように，しきい値の設定方法として判別分析法を用いた[9]. これは，二値化する際，クラス間分散とクラス内分散との比である分離度が最大となる最適しきい値 th を分析する手法である．8bit（256階調）の濃淡画像の二値化における最適しきい値を求める際，クラス 1 を輝度値 $0 \sim th-1$，画素数n_1，平均輝度値$\overline{f_1}$，分散σ_1^2，クラス2を輝度値$th \sim 255$，画素数n_2，平均輝度値$\overline{f_2}$，分散σ_2^2，輝度値 f を持つ画素の数をn_f とすると,

$$\sigma_1^2 = \frac{\sum_{f=0}^{th} (f - \overline{f_1})^2}{n_1} \tag{4}$$

$$\sigma_2^2 = \frac{\sum_{f=th}^{255} (f - \overline{f_2})^2}{n_2} \tag{5}$$

また，全画素の平均値を$\overline{f}$ とするとクラス間分散σ_B^2およびクラス内分散σ_W^2 は次式で表される.

$$\sigma_B^2 = \frac{n_1(\overline{f_1} - \overline{f})^2 + n_2(\overline{f_2} - \overline{f})^2}{n_1 + n_2} \tag{6}$$

$$\sigma_W^2 = \frac{n_1\sigma_1^2 + n_2\sigma_2^2}{n_1 + n_2} \tag{7}$$

σ_B^2 / σ_W^2 の値が最大となる輝度値が計算上の最適しきい値 th となる．今回，**図-12**のおける最適しきい値は$th = 6$であり，**図-14**に示すとおり，粉じん散乱光部分をうまく抽出できていることがわかる.

b) ノイズ低減処理

次に，浮遊粉じんのない粉じん濃度0.0mg/m^{3}における動画像に対し同様の時間差分処理，画像補正，二値化処理を行った．その結果を**図-15**に示す．**図-15**においてカメラ前方に浮遊粉じんは存在していないため，図中に写っている微小白点は全てノイズと考えられる．このノイズを除去するため，モルフォロジー処理の適用した．モルフォロジー処理とは, **図-16**に示すように画像内の形を変える処理のことであり，構造要素と呼ばれる図形（本研究では円形）を仮定した上で，収縮処理と呼ばれる領域の外にでないように構造要素が移動した際の要素の原点が通過しうる領域を抽出する演算と，膨張処理と呼ばれる構造要素の原点を図形内で移動させた時の構造要素が通過しうる領域を計算する演算である[10]，具体的には，まず微小白点を消去できる程度まで収縮処理を実施し，その後，元のサイズまで膨張処理を行う.

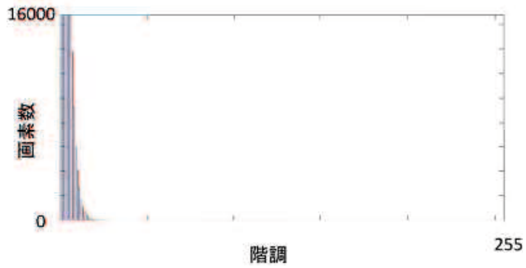


図-13 時間差分画像ヒストグラム

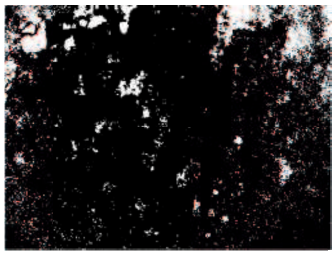


図-14 二値化処理の結果

図-15 0.0mg/m^{3}における二値化処理の結果

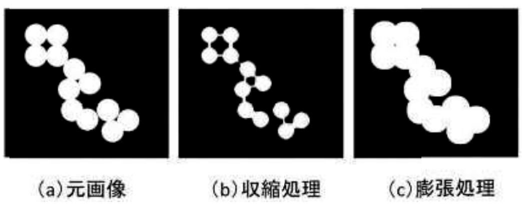


図-16 モルフォロジー処理の例

図-14および図-15に対してモルフォロジー処理を行った結果を図-17に示す. 図-14と図-17(a)および図-15と図-17(b)を比較すると, 画像内のノイズを上手く除去できていることが分かる.

(5) 粉じん散乱光数の算出

図-6にも示したように, 実際の粉じん濃度は低い値であるにも関わらず, DMS-Sでは極端に高い粉じん濃度を示すというはずれ値問題があった. これは, 写真撮影時レンズ極近傍に存在した1~数個の粉じんにフラッシュが照射, 散乱され, 撮影画像内に大きな白斑として写ったことが原因である. 粉じん濃度測定の自動化を考えると, この現象を根本的に排除することは困難であるため, 新たな処理として粉じん散乱光領域を分割し, 画像内の粉じんの個数を算出する方法を提案する.

粉じん散乱光領域の分割は, 画像補正後に行う. 図-17の状態では, 画像の値が0と1のみなので, まず距離変換を行い, 背景からの距離により値が連続的に変化する新たな距離変換画像を作る. 距離変換とは図形内の白画素（輝度値255）に対し背景（輝度値0）からの最短距離を計算するアルゴリズムである [11]. 具体的には, 本論文ではユークリッド距離,

$$d_e = \sqrt{(i-p)^2 + (i-q)^2} \tag{8}$$

を用いる. ここで, d_eは画像上の任意の白点（i, j）と最短距離にある黒点（p, q）間の距離である.

そして, 距離変換画像から領域分割処理を行い, 粉じん領域を分割する. 領域分割手法として, 本手法ではWatershed アルゴリズムを適用する. Watershed アルゴリズムを用いた領域分割法は, 距離変換画像を地形とみなし, その極大部分から境界を徐々に拡大することで輝度値画像から粉じん領域を分割する [12]. 他の領域分割手法が, 始点の選択法, 成長の手順に任意性が有り, 同じ画像を処理しても複数の異なる結果が得られる可能性があるのに対し, この処理では, 作業始点は画像によって一意に与えられ, また, 成長の手順も地形を想定した水域の広がりを模擬するため, より一意性が高い. 図-17(a)に対して領域分割処理を行った結果を図-18に示す. なお図-18における領域数すなわち粉じんの個数（以下, "粉じん散乱光個数" と呼ぶ.）は90であり, 重なりあう粉じんを分割できていることが分かる. また, 図-8のようにレンズ極近傍に粉じんが存在している場合における領域分割結果を図-19に示す. 画像取得時のデジタル粉じん計での粉じん濃度は0.4mg/m^{3}であり, 図-18の結果よりも低粉じん濃度であると判断できる. なお, 図-18, 図-19において, 領域の分割状況をよりわかりやすくすることを目的に, 左から右に向かい青から赤で着色している.

(6) 特徴量の検討

(2)~(5)までの処理により, 画像から得られる特徴量として, 粉じん散乱光領域の面積（画素）（以下, 粉じん散乱光部分面積" と呼ぶ.）および粉じん散乱光個数の組み合わせを検討することとした. これらは, 図-8のようにレンズ極近傍に粉じんが存在している場合でも粉じん濃度を正しく評価できるため, 長期的な現場適用に適している. そこで, 粉じん散乱光部分面積, 粉じん散乱光個数を掛けあわせた値を新たな特徴量（以下, "新特徴量" と呼ぶ.）として提案する.

(7) 新特徴量から粉じん濃度への変換の検討

新特徴量は, カメラ前方に存在する粉じん散乱光個数により変動する. 粉じん散乱光個数が少ない, つまり粉じん濃度が低い場合, 新特徴量も小さい値を示し, 粉じん散乱光個数が多い, つまり粉じん濃度が高い場合には新特徴量も大きい値を示す. 背景の影響を受けないため, 撮像系の条件を固定した場合, 単純な数理モデルにより新特徴量から粉じん濃度へ変換することが可能であると考えられる. 具体的な変換モデルについては4. (2)で述べ

(a) 図-14の処理結果　　(b) 図-15の処理結果

図-17 二値化画像に対するノイズ低減処理結果

図-18 領域分割画像

図-19 領域分割画像(2)

る．以上をまとめ，本論文で提案する動画像処理による簡易粉じん濃度測定手順を**図-20** に示す．

4. ネットワークカメラを用いた粉じん濃度測定法

(1) 概要

ネットワークカメラ（Network Camera）とは，それ自体に固有の IP のアドレスが割り振られており，ネットワークを通じてどこからでも映像を確認できるビデオカメラの総称であり，トンネル坑内の作業状況を坑外でも簡単に把握することができるため，急激にその利用現場が増えている．本研究では，このネットワークカメラへの追加機能として，定点の粉じん測定機能の追加を検討する．すなわち，ネットワークカメラと LED ライトを組み合わせた粉じん散乱光取得部と前述の動画像処理をプログラムとして組み込んだパソコンを組み合わせ， 前章で提案した動画像処理による粉じん濃度測定法をリアルタイムで行う，ネットワークカメラを用いた定点常時粉じん濃度測定法（Dust Monitoring System by IP Camera，以下 “DMS-IPC” と呼ぶ．）を提案する．

(2) DMS-IPC の有用性の検証

前述の開削トンネル建設現場で採取した発生粉じんを用いた室内実験により DMS-IPC の有用性を検証する．室内実験に用いた粉じん散乱光取得部の構成を**図-21** に示す．本実験では，粉じん散乱光動画像に同期させた粉じん濃度を得るために，ネットワークカメラ近傍にデジタル粉じん計を設置し，そのロギング機能を用い 1 秒毎の粉じん濃度を取得し，それを正解値とする．デジタル粉じん計による粉じん-濃度測定結果を**図-22** に示す．粉じん濃度は 0.1～25mg/m^3 と必要十分の濃度範囲が得られており，DMS-IPC の有用性検証に十分なデータが取得できていることがわかる．

ネットワークカメラ画像を前章で述べた画像処理を行い一秒ごとに新特徴量を測定する．そして，測定データを識別機構築用の学習データ（データ数 : 276）と，構築された識別機評価用のテストデータ（データ数 : 84）に分ける．その上で，学習データにおける新特徴量とデジタル粉じん計による測定粉じん濃度との相関を**図-23** に示す．図から明らかなように，新特徴量と測定粉じん濃度は，全体によい相関性が認められる．特に，粉じん濃度の管理基準である 3mg/m^3 以下の精度はよい．そこで，数理モデルとして最もシンプルな線形回帰式を当てはめると，下式を得た．

$$(\text{換算粉じん濃度}) = 2.311\ln(\text{新特徴量}) - 21.902 \qquad (9)$$

次に，テストデータを用いて，DMS-IPC の有用性を検証する．テストデータから新特徴量を算出し，式(9)によ

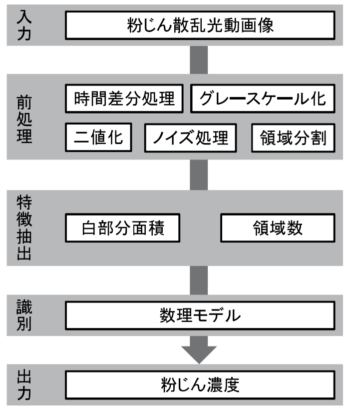


図-20 動画像処理による粉じん濃度測定手順

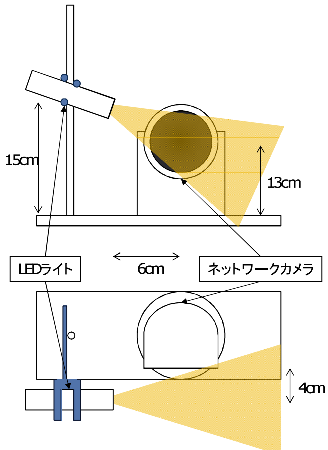


図-21 粉じん散乱光取得部構成

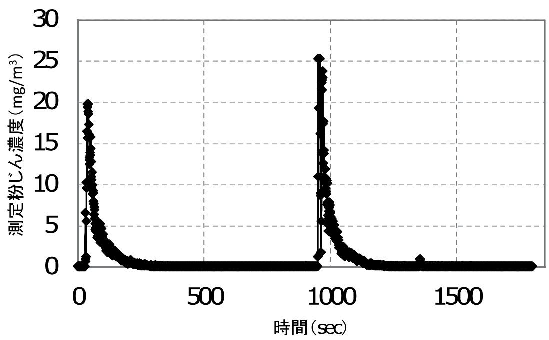


図-22 デジタル粉じん計による経時測定結果

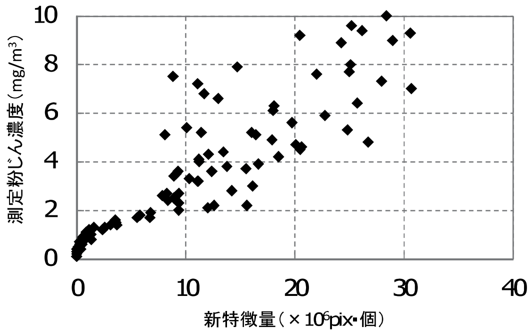


図-23 学習データに対する対数近似結果

り粉じん濃度に換算し得られた換算粉じん濃度と，デジタル粉じん計による測定粉じん濃度の相関図を**図-24** に示す．なお，式(9)を用いて，**図-22** の経時粉じん濃度を換算すると**図-25** となる．図からわかるように，粉じん濃度の減衰状況も表現できていることがわかる．なお，13mg/m^3 以上に関しては表示を省略している．

換算粉じん濃度とデジタル粉じん計による測定粉じん濃度の相関性を調べるため，次式を用いて，**図-24** の相関係数を求めた．

$$\rho = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})^2}\left(\frac{\sigma_x}{\sigma_y}\right) \tag{10}$$

ここで，$\bar{x}$ ：測定粉じん濃度 x の標本平均

$\bar{y}$ ：換算粉じん濃度 y の標本平均

σ_x ：測定粉じん濃度 x の標準偏差

σ_y ：換算粉じん濃度 y の標準偏差

なお, 相関係数 ρ は 1.0 に近いほど相関性が強く測定精度が高いことを表しており, 一般的に 0.8 以上で高精度とされている．**図-24** より得た相関係数は 0.85 であり，この結果から換算粉じん濃度とデジタル粉じん計による測定粉じん濃度の相関性は高いことがわかる．

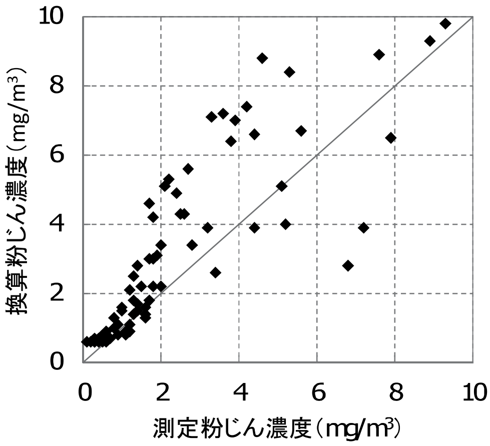


図-24　測定粉じん濃度と換算粉じん濃度の相関図

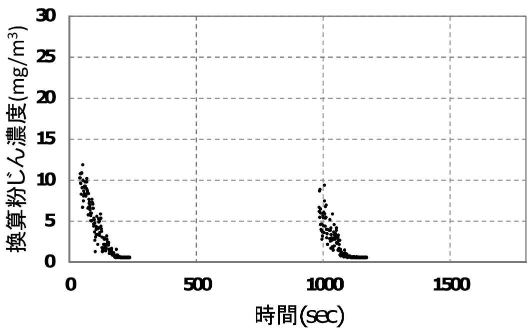


図-25　換算粉じん濃度経時変化図

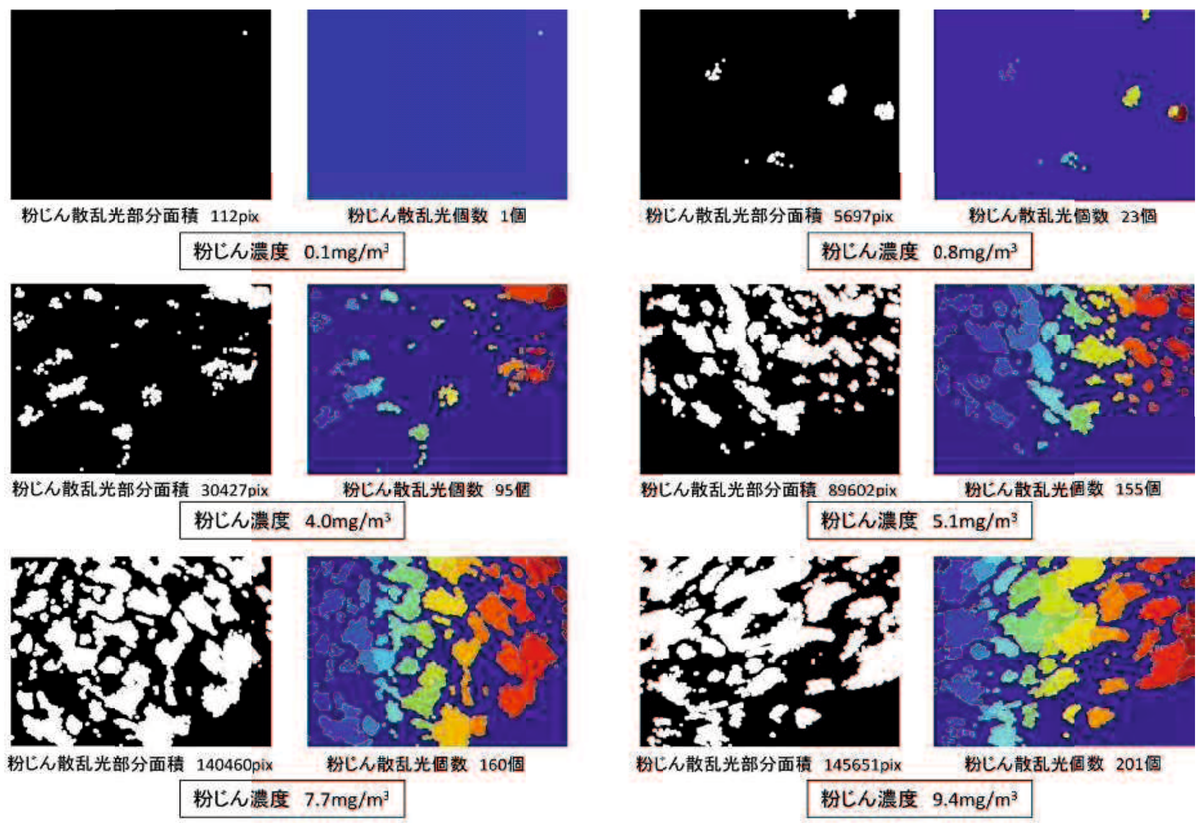


図-26　ネットワークカメラによる粉じん散乱光部分抽出結果の一例

また，**図-26**は，ネットワークカメラからの画像をパソコン上でリアルタイムに画像処理を行い，粉じん散乱光を抽出した結果の一例である．この図からわかるように，デジタル粉じん計による測定粉じん濃度の変化に対応して，粉じん散乱光部分面積および粉じん散乱光個数ともに変化していることがわかる．

5. 結論

本研究では，既往研究において提案されたスマートフォンを用いた簡易粉じん濃度測定法をインド・バンガロールメトロ駅舎部開削工事現場において適用した．その際，従来の方法は暗環境下での適用を目的とした方法であったため，ダストボックスを考案しボックス内で散乱光を得る方法を新たに考案した．しかし，そのままの状態では長期間計測において，簡易粉じん測定値がはずれ値や一定値をしめす結果が生じたため，ブラックパネルの黒色度の経時変化に着目し，異なる表面状態を持つ3枚のブラックパネルを用いて行った現場実験を実施した．その結果，スマートフォンを用いた簡易粉じん測定法に採用されている従来の画像特徴量（画像輝度平均値，画像輝度分散値）では背景の変化に敏感であり，特徴量として長期間適用に問題が多いことが分かった．

そこで，安定的な粉じん測定を行うために，粉じん散乱光動画像を採用し，時間差分処理，グレースケール化，二値化，モルフォロジー処理，距離変換，Watershed処理といった種々の動画像処理を適用することで，新特徴量（粉じん散乱光部分面積および粉じん散乱光個数）を考案し，既往手法をさらに発展させたネットワークカメラによる定点常時粉じん濃度測定法を提案した．

以下に本研究で得られた知見を述べる．

1) 本研究手法による画像処理をリアルタイムに実施することにより，背景の影響は，ほぼ完全に除去することが可能である．
2) 人工知能による学習を行わなくても，新たな特徴量（粉じん散乱光部分面積および粉じん散乱光個数）を回帰分析した結果．最小二乗法に基づく線形近似で，本手法による換算粉じん濃度とデジタル粉じん計による測定粉じん濃度との間に高い相関の数理モデルが構築できる．
3) ネットワークカメラによる取得動画像に対して動画像処理による粉じん濃度測定法を適用することで，定位置における常時粉じん濃度測定を実現できる．

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DUST MONITORING SYSTEM BY NETWORK CAMERA ON VIDEO PROCESSING

Reiko ABE, Yuki SASAKI and Masato SHINJI

This paper treats with the practical problems of the use of simple dust monitoring system by using the smartphone at the open excavation site of the metro station construction site and suggests the new dust monitoring system by network camera which is widespread use at the tunnel construction site. To eliminate the noise from the influence of the black panel, image processing algorithm has applied. In addition, new feature value is introduced to continue the stable dust density measurements. The laboratory tests show that proposed system has higher accuracy than the current system and satisfying performance as a simple dust measurement system.

土木学会論文集記載事項の訂正

土木学会論文集 F1（トンネル工学）, Vol. 70, No. 1, p.15, (2014) に誤りがありましたので，下記の通り訂正いたします.

記

誤　論文題目：　動画像処理理に基づくネットワークカメラによる簡易粉じん濃度測定法

正　論文題目：　動画像処理に基づくネットワークカメラによる簡易粉じん濃度測定法

以上