Research paper

Evaluation of mist diffusion and application of water tube for dust control in blasting demolition

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Abstract

In this study, a water tube with detonating cord has been devised for the effective control of dust during explosive demolition of buildings or structures at construction sites. The AUTODYN program was applied for the numerical analysis and description of the mist diffusion process in the water tube. The analysis results were compared with the experimental results. The dust reduction performance using the water tube was evaluated at a tunnel site in one-directional airflow by measuring the total suspended particles, PM10, and PM2.5 of dust and by comparing the application case of the water tube with a non-application case. In conclusion, it was found out in this study that the water tube for the suggested mist diffusion method with a detonating cord has considerable strength. It can be easily installed onsite and a sequential arrangement is allowed. Moreover, the use of the water tube was highly effective in controlling the dust owing to the fine water droplets produced by high-velocity water expansion.

Keywords: explosive demolition, dust, detonating cord, water tube, AUTODYN

1. Introduction

Environmentally hazardous factors in blasting works during demolition of structures can be classified into noise, vibration, and dust. Among them, dust is a typical nuisance during blasting demolition as it causes respiratory problems. The dust from blasting of structures in urban areas might be less compared to that from other industries. However, the actual increase in complaints from people makes the application of large-scale earthwork and blasting of structures in urban and populous areas difficult. These complaints may be considered obstacles in the development of the blasting industry.

If a large number of fine droplets are to be generated without a spray nozzle, an instantly raised high pressure is required. In previous studies, a method of producing mist by using explosives has been studied.

Dust capture is most effective when dust particles collide with water droplets of equivalent size. Instant pressure is required to generate diffusion of the fine mist if a spray nozzle is not used. Previous studies in this field have investigated the application of explosives as a mechanism to provide the instant pressure required. Both Li[1] and Stefanski[2] conducted experiments to assess the water mist diffusion through blasting. In these studies, both authors assessed the fine mist diffusion for suppression control by first comparing the performance of spherical water bags with explosives with that of large-scale water bags with explosives.

Liu[3] and Han[4] measured the spraying radius and spraying speed of mist as a function of the volume of charge, shape of charge, thickness of water bag, and length-to-diameter ratio by analyzing the image obtained from explosion experiments using a spherical water bag. They also studied the detonation dust reduction by applying the measurements to the explosion and demolition site of structures.

In the study prior to the present study, Ko et al.[5]

suggested thorough evaluation experiments for spray behavior per factor, such as the volume of charge, diameter of the tube, and the position of inner explosion of the water tube. The optimal condition of the water tube must be 200 mm in diameter and 20 g m^{-1} in the charge of detonating cord. He also stated that when the explosive charge was installed at the bottom cross section of the inner tube, the aspect ratio of the cross section of spray diffusion for the bottom charge should be relatively more slender than that of the central charge to help in the formation of a water curtain. When the water tube is installed inside the structure of the blasting demolition object, the spray height may not be critical. However, for the ground outside the structure, response to the dust diffusion produced by collision of the structure with the ground resulting from the structure collapse after blasting. Thus, as a primary direct blocking resulting from the formation of the water curtain, absorption of subsequent dust and spray are required. The spray height and duration of spray can be important parameters. Ng et al.[6] and Roman et al.[7] conducted studies on blocking of coal dust resulting from the formation of spraying barrier at coal mines and demonstrated the effects of water curtain on dust reduction. In the present study, verification experiments were conducted on the mist diffusion of the charge at the center and bottom inside the water tube by the application of optimum conditions of water tube proposed by Ko et al. Mist diffusion values per charge position were averaged and schematically shown. The pressure and internal energy behavior as a function of differences in charge position inside the tube were subjected to numerical analysis using the AUTODYN Euler Solver.

2. Experiments on mist behavior with water tube

2.1 Comparative experiments on charge positions

Figure 1 shows the shapes of water tubes and charge positions (bottom charge or central charge).

Mist diffusion experiments were conducted five times each for the central and bottom inside charge positions with 200 mm water tube diameter and 20 g m^{-1} charge of the detonating cord. Based on the experimental image analysis, the maximum height of mist diffusion, aspect ratio of diffusion area, and mist duration per charge position were derived (Table 1).

The initial mist diffusion rates in the vertical direction were calculated based on the time until the jet splash column is split into fine mist. The aspect ratio of the mist diffusion across the area for the bottom charge averaged 5.7, being relatively slender compared with the water tube with central charge. The stage of reaching the splitting condition from the formation of the splash column quickly proceeded, showing a higher average initial diffusion rate of 117 ms^{-1} than that of the central charge. The mist duration was set as the dispersion time after floating of the mist based on the time of reaching the maximum value of diffusion. The average diffusion durations for the central and bottom charges were approximately 2 second and 3.3 second, respectively. Figures 2 and 3 show the shapes and heights of mist for the central and bottom charges.

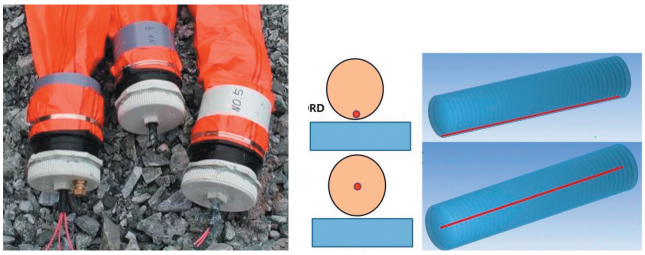


Figure 1 Form of water tube and explosion position of charge (bottom charge & central charge).

Table 1 Experimental result of water tube mist diffusion behavior.

Charge position	Case No.	Diffusion height [m]	Aspect ratio	Mist floating time [s]	Jet splash time [s]	Initial jet velocity [m s^{-1}]
Bottom	1	25.3	5.6	3.81	0.038	131
	2	26.5	7.5	4.05	0.040	124
	3	21.6	5.5	3.10	0.043	117
	4	19.4	4.7	2.14	0.052	95
	5	24.3	5.1	3.33	0.042	119
Average		23.4	5.7	3.29	0.043	117
Central	1	18.7	2.6	2.12	0.060	84
	2	15.5	1.6	2.00	0.063	79
	3	18.2	4.2	2.38	0.060	83
	4	17.5	2.0	1.90	0.062	81
	5	17.3	2.3	1.90	0.067	75
Average		17.4	2.5	2.06	0.062	80

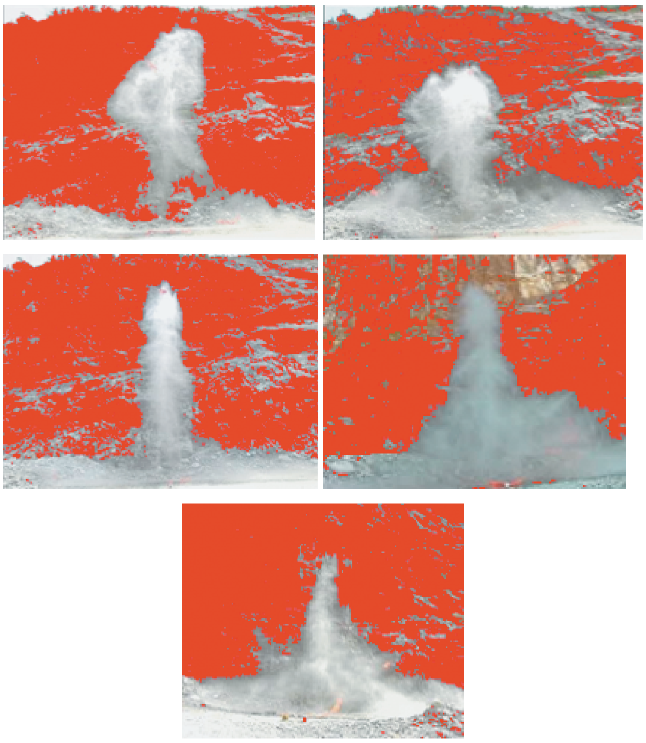


Figure 2 Cross-sectional form of mist diffusion (central charge).

2.2 Analysis of initial jet for bottom charge

For the bottom charge, the expansion of the jet pin structure was confirmed to be diffused predominantly in the vertical direction. Based on the image analysis of the

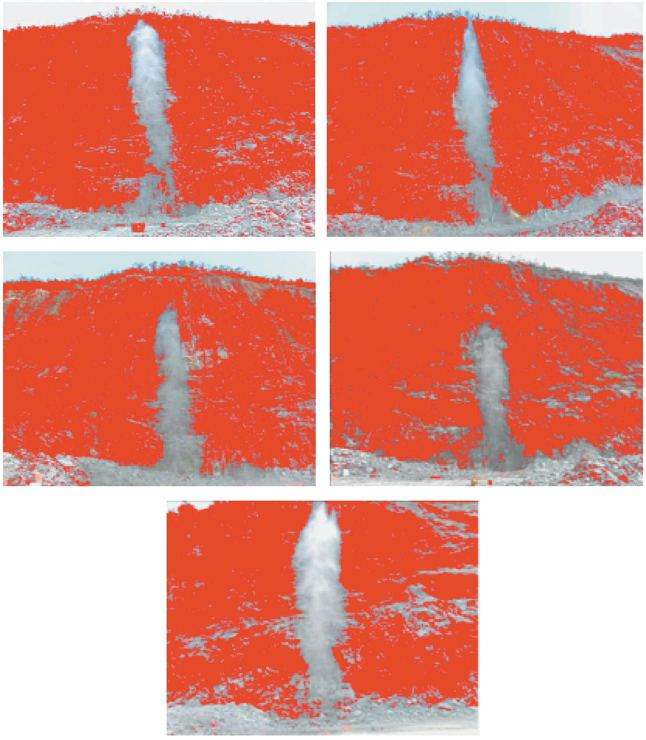


Figure 3 Cross-sectional form of mist diffusion (bottom charge).

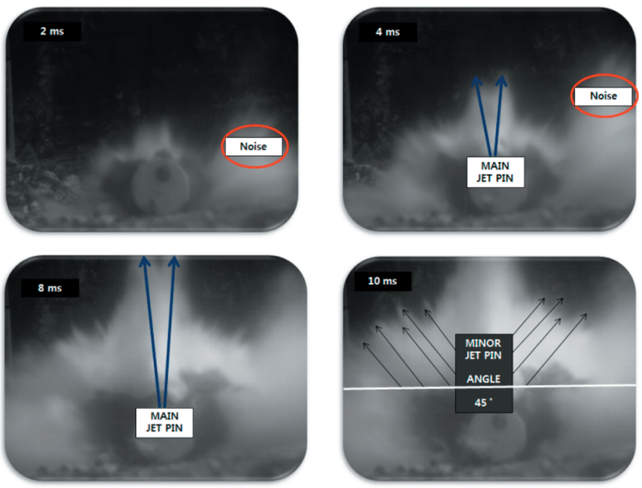


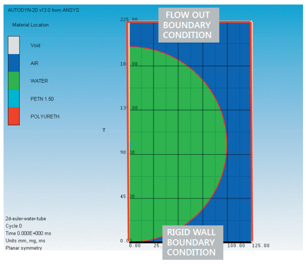
Figure 4 Jet pin movement after explosion for bottom charge.

explosion process in the water tube for the bottom charge using a high-speed camera at 1000 fps, a major jet pin in the vertical direction was formed at approximately 3 millisecond after the explosion, proceeding gradually until being synthesized by a combination of two main jet pins between 8–9 millisecond. Subsequently, multiple minor jet pins progressed at 45° with respect to the ground surface as shown in Figure 4. At the initial stage of explosion, noise diffusion occurred, which is considered to have been affected in some section of the detonating cord installed inside by irregularities of the ground. Thus, ground irregularities must be taken into account during installation of the water tube.

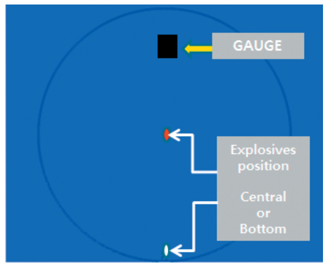
3. AUTODYN numerical analysis of water tube

3.1 Analysis model

To solve the reflection problems at the boundary, the



(a) Boundary condition



(b) Pressure gauge and explosives position

Figure 5 AUTODYN water tube model.

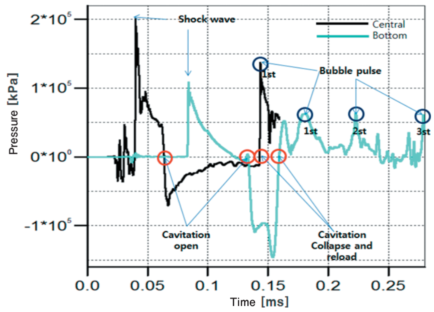


Figure 6 Time history of shock wave and gas bubble pressure pulse (Water tube, AUTODYN).

AUTODYN Eulerian code provides users with flow out of boundary conditions. Because the water tube is usually arranged inside the structure or on the ground, the rigid wall was set at the bottom boundary face in the present analysis to consider the reflections caused by the ground. For the AUTODYN Euler solver, the initial boundary value was zero without requiring input of additional boundary conditions to set up the rigid wall.

The atmospheric space boundary for the tube was set with flow-out boundary conditions for the infinite flow. For smooth analysis of speeds, a symmetrical model was used after modeling only half of the entire water tube, and a total of 704,876 elements were used for the analysis (Figure 5).

3.2 Analysis results

The explosive charge converted to gas by the explosion reaction inside the water tube formed gas bubbles of high pressure after the occurrence of shock waves. The high-pressure bubbles exhibited a vertical migration movement owing to the pulsation motion with periodic expansion and shrinkage. The closing of cavitation and the resulting inertia in the direction of the atmospheric boundary face direction owing to such closing until the external skin of tube was fully vented because of the imbalance with the surrounding water pressure.

Figure 6 shows the time history of the pressure pulse time of the gas bubble together with the shock waves for the central and bottom charge in the water tube. For the initial shock waves, a higher pressure was observed on the central charge than on the bottom charge, and the central charge was relatively close to the gauge position. Pulsating motion was observed, where pressure pulses were released from 3 up to 270 times. As the time, where complete opening of the tube outer skin was achieved for

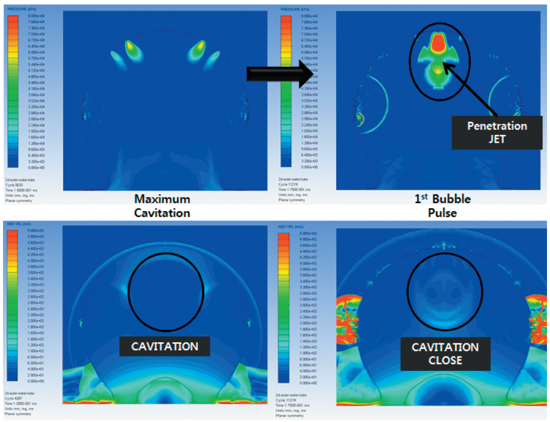


Figure 7 Pressure behavior of bottom charge (d : 200 mm).

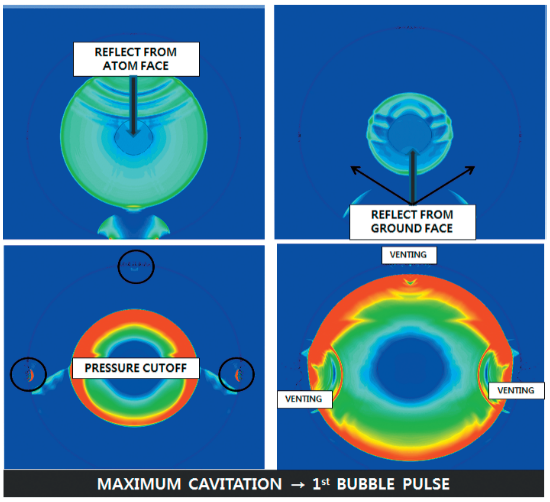


Figure 8 Pressure behavior of central charge (d : 200 mm).

the bottom charge, whereas no continuous pressure pulses were produced by the early opening of the tube outer skin.

The pulsating movement periodically released pressure pulses as the explosion cavities were collapsed at the minimum shrinkage point of the pressure in every period. In addition, for the water tube with bottom charge, the synthesis form of the shock wave and the reflected wave proceeded almost simultaneously toward the tube top owing to the effect of the ground after explosion. Therefore, as no superposition of the incident shockwave and reflected wave from the ground occurred, there would be no effect of pressure blocking. The jet was expected to penetrate as the accumulated vertical jet rose from explosion cavities at the tube bottom, while floating and deformed bubbles were propagated in the direction of the atmospheric boundary face on top of the water tube (Figure 7).

Figure 8 shows the effect of the opening of the outer skin on the side resulting from the propagation of shock waves and superposition of reflected wave for the water tube with central charge. For the water tube, it was confirmed that the form of the spraying angle for mist diffusion could vary with the explosion position of the detonating cord.

4. Experiments on dust reduction with water tube

As the control of meteorological conditions such as wind velocity, wind direction, etc., which has large effects on flow of dust particles, is not allowed in outdoor situations, the prohibited conditions, such as meteorological states, should be excluded to obtain reproducible results for the evaluation of dust reduction capabilities of water. Compared with outdoor conditions, the case of underground mining tunnels may be considered as conditions relatively allowing minimization of the effects of surrounding conditions. In the present experiments, dust was artificially generated in underground mining tunnels by using explosives and dust bags. Then, the dust reduction performance resulting from the formation of water curtain in the water tube was evaluated through measurements of total suspended particles (TSP), PM2.5, and PM10 for each case of application and non-application of the water tube.

4.1 Installation of water tube

A jet fan was installed at the tip of the experimental tunnel so that the dust generated after the explosion of the dust bag was induced in one direction only. The wind volume flow rate for the employed jet fan was 1020 m^3 min^{-1} and the rotating speed of the fan was 1800 rpm. The water tube was installed as shown in Figure 9 and Figure 10. The dust bag was positioned 10 m away from the fan and was hung to the pipe angle at a height of 1.8 m for smooth diffusion of dust. Three units of dust concentration meters were installed at a spacing of 15 m from the dust bag without application of the water tube to obtain the basic data on dust concentration for the evaluation of dust reduction capability of the water tube in the tunnel. The experiments were conducted with the following setup : for the first stage, the water tube was installed at 20 m from the fan ; for the 2nd stage at 30 m, while for the 3rd stage at 40 m (Figure 10 (b)).

The time difference in the explosion was 0 millisecond for the dust bag, 800 millisecond for the first stage of water tube considering the initial diffusion rate of the dust bag, and 1000 millisecond per stage of the water tube. In addition, the case considering wind velocity attenuation per distance of the experimental tunnel was applied, and the dust reduction performance was compared with the case of simple time difference intervals by extending the time difference intervals for the experiments.

4.2 Test results and review thereof

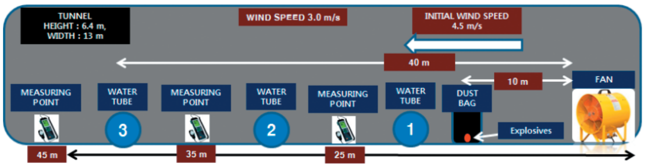
By using 3 units of Dust Trak DRX as the real-time measuring instrument for dust concentrations of the light scattering method, the dust concentration values in each experiment were measured at intervals of 1 s up to 15 minute after explosion. Three tests were performed per experimental case for a total of 15 experiments. The maximum dust concentration values at each measuring point per application to the water tube stage are summarized in Table 2. The dust generated floated for approximately 10 minute after explosion and returned to

(a) 1-stage water tube

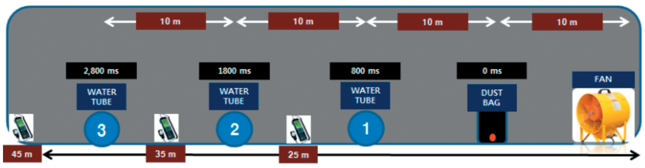
(b) 2-stage water tube

(c) 3-stage water tube

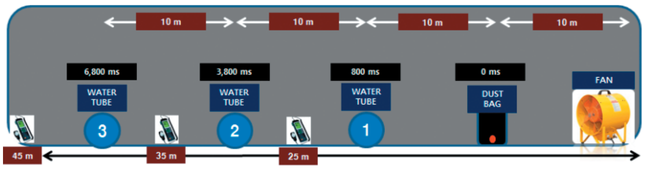
Figure 9 Site installation image of water tube.



(a) Position of water tube and dust measuring instrument



(b) Time difference for explosion



(c) Time difference for explosion (considering wind speed attenuation)

Figure 10 Schematic diagram of dust reduction experiment for unidirectional airflow with water tube.

the usual dust concentration value in the tunnel.

When the single-stage water tube positioned at 10 m away from the dust bag with the explosion time difference of 800 millisecond was applied, the TSP for the maximum value of initial dust concentration was 144,500 μg m^{-3} with PM10 of 90,900 μg m^{-3} and PM2.5 of 27,255 μg m^{-3} because of the formation of the water curtain. Then, the TSP concentration at the second measuring point was slightly increased because of the elimination of the water curtain, following which, it showed a tendency to decrease at the point of 35 m. Through a comparison of the single-stage application with TSP on non-application of the water tube, the offset of kinetic energy TSP by the progressing dust could be confirmed as a result of the formation of the water curtain in the water tube.

Table 2 Result of dust measurement for individual case.

Distance from dust bag [m]	Maximum amount of dust per dust bag [μg m^{-3}]			Arrangement
	TSP	PM10	PM2.5	
15	172,500	100,600	35,550	without water tube
25	236,000	96,300	36,000	
35	243,000	80,250	30,000	
15	144,500	90,900	27,255	with water tube 1 stage
25	171,500	76,500	34,050	
35	145,775	65,068	28,943	
15	141,500	85,000	25,790	with water tube 2 stage
25	136,540	51,000	30,290	
35	123,250	43,350	25,747	
15	137,000	79,000	20,700	with water tube 3 stage
25	115,000	47,600	31,200	
35	97,750	37,825	22,000	
15	148,000	87,420	21,354	Considering wind speed decrease
25	87,200	35,000	28,600	
35	74,120	29,750	19,310	

Although there may be some effects on dust sedimentation as a function of distance, the maximum concentrations as a function the number of installed stages of water tube at the third measuring point showed a clear difference. Such observation may be an example showing that multi-stage arrangement of the water tube is effective for fine dust. When the case with the application of a three-stage arrangement of water tubes and simple time difference of 1000 millisecond was compared with the case having application of explosion time differences for the water tube of 800, 4000, and 7000 millisecond with wind velocity attenuation, the time difference in design, considering the wind velocity attenuation, exhibited a high dust reduction performance.

By setting the average value for the measured concentration with the water tube not installed as the reference value, the extents of dust reduction at 35 m away from the dust bag were evaluated as shown in Figure 11. The dust reduction rate was 40% based on TSP with the application of only one stage of the water tube inside the tunnel, 19% based on PM10, and 4% based on PM2.5. For the application of two stages of water tube, the dust reduction rate was 49% based on TSP, 46% based on PM10, and 14% based on PM2.5. For the application of three stages of water tube, the dust reduction rate was 60% based on TSP, 53% based on PM10, and 27% based on PM2.5. For the experiments that consider the wind velocity attenuation, the dust reduction rate was 69% based on TSP, 63% based on PM10, and 36% based on PM 2.5, showing a difference from the case with application of simple time difference.

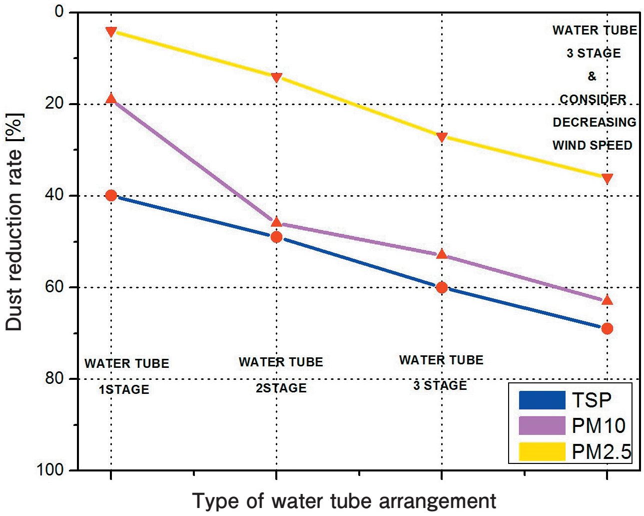


Figure11 Dust reduction rate of water tube per experimental case.

5. Conclusion

The water tube combined with the detonation cord, as a reduction method for explosive demolition of dust, as proposed in the present study, can be considered more efficient compared to other methods of dust reduction. This is based on the aspects of applicability to the demolition site and economy as well as the dust reduction performance. It can be considered as a dust reduction method specialized for explosive demolition sites. The conclusions of the present study may be summarized as follows :

1) For the water tube with bottom charge, the shock wave and reflected wave almost simultaneously progressed towards the top of the tube in the form of combined forces owing to the ground effects after explosion. Because no superposition of the incident shock wave and reflected wave from the ground occurred, there was no effect of pressure blocking. As the bubbles floated and changed, the accumulated jets vertically rose from the explosion cavities at the tube bottom while the bubbles were floating and were deformed. They were propagated in the direction of the atmospheric boundary face on the top of the water tube in the form of penetration. For the water tube, the shape of the spraying angle in mist diffusion may vary with the explosion position of the detonating cord.

2) When the water tube is installed on the outskirts of the explosive demolition object, the detonating cord should be installed on the inside bottom of the water tube for the formation of the water curtain having maximized height of mist diffusion.

3) When the number of installed stages of the water tube is increased to form the multi-stage water curtain, the reduction effect of ultrafine dust may be enhanced. The design should be performed by considering installation time and economy. The separation distance between stages of the water tube should be set within 10 m and the water tube in the first stage should be installed close to the expected position of occurrence of explosion dust.

4) For the time difference design of the explosion per stage of the water tube, the expected values for production of wind velocities owing to explosive wind pressures, the prevailing direction, and velocity of wind direction at the site shall be considered. The time difference for explosion per stage of water tube should be exponentially designed to correspond to the predicted attenuation of the initial explosive wind pressure progression.

Acknowledgements

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