Research paper

Explosive demolition of a cylindrical shell structure constructed in the slip form method

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Abstract

Recently, the number of cement silos that must be demolished due to unsatisfactory functional conditions has increased. A cylindrical shell structure that is constructed in the slip form method, a cement silo is composed of an internal structure that consists of a cone and ring girder and an external structure that consists of a cylindrical shell. As these two structures are two separate structures and have reciprocal effects on collapsing movements, it is not easy to apply explosive demolition. The design and execution of a method used to demolish a 10,000 ton level cylindrical cement silo by blasting were described in this study ; moreover, the effects of ground vibration and dust were examined.

Keywords : explosive demolition, cylindrical shell structure, slip form method, felling method, cement silo.

1. Introduction

Recently, the number of industrial structures that must be demolished due to structural deterioration and unsatisfactory functional conditions has been increasing. These industrial structures have diverse shapes and forms depending on the equipped facilities, and are large in scale, have high strength and high rigidity[1), 2)].

Youngjong Island shipping base was constructed in 1997 to facilitate the marine supply of cement for the construction of Incheon International Airport. However, its operation was suspended and its function as a shipping base was lost due to the land supply of cement since 2001, making it a target for demolition. The target structures for explosive demolition are cylindrical reinforced concrete cement silos, including Silo No.1 (15,000 tons) and Silo No.2 (10,000 tons) at this shipping base.

A silo is constructed in slip form method as a cylindrical reinforced concrete shell structure, and is a structure without an expansion joint. The slip form method is a typical construction method of a cylindrical reinforced concrete silo. Its size, structural characteristics and construction method differ from the size, structural characteristics and construction method of a chimney, which is also a cylindrical structure[3)~5)]. In addition, it has a relatively small ratio of height to diameter, and as its internal structure consisting of a cone and a ring girder and its external structure consisting of cylindrical reinforced concrete shell are separated from each other, it is not easy to demolish by blasting.

In this study, the method of demolishing the 10,000 ton level cylindrical cement silo No.2, a cylindrical shell structure constructed in the slip form method, and its execution in the removal work of Youngjong Island shipping base will be described, and the effects of ground vibration and dust will be examined.

2. Plan for explosive demolition

2.1 Formation of cement silo

Figures 1 and 2 show the view and elevation plan, respectively, of silo No.1 and silo No.2. The right silo is No.1 and the other is No.2, which is the target structure for explosive demolition. The external diameter and height of silo No.1 are 24.9 m and 36.1 m, respectively, and the external diameter and height of silo No.2 are 22.9 m and 33.3 m, respectively. These two silos are composed of a reinforced concrete structure and a steel structure as a cylindrical shell structure, and the distance between the outer walls is 3.6 m.

Fig. 1 View of the target structure for explosive demolition.

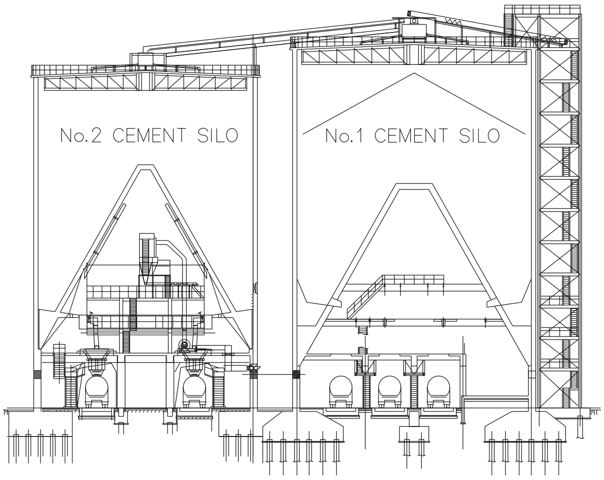


Fig. 2 Elevation plan of the target structure for explosive demolition.

Styrofoam is placed in the 100 mm expansion gap between the cylindrical shell and the ring girder of silo No.2 that will be described in this study, the maximum height of the ring girder is approximately 4 m, and the height of the ring girder and the cone, which are the internal structure, is approximately 18.5 m, representing 55.6% of the total height of the silo. The ring girder and the cone, which are the internal structure, are separated from the cylindrical shell, delivering independent movement. The height to diameter ratio of silo No.2 is approximately 1.45, and the thickness of the cylindrical shell is 450 mm.

2.2 The surrounding conditions

The surrounding conditions of the target structure of explosive demolition are as shown in Fig. 3. Surrounding

Fig. 3 Surrounding conditions.

elements include a docking facility and a connected transfer bridge for transporting cement to the north of silo No.2, and a pier for transporting sand to the northwest of silo No.2. The shore protection from the north to the south is covered with armor stone, and a military barrack, which is a concrete block structure, is located to the southwest. Table 1 shows the formation and specifications of surrounding structures.

2.3 Selection of a demolition method and collapsing direction

As silo No.2, which is the target structure for explosive demolition, has a small height to diameter ratio, and the cylindrical shell and the ring girder are separated, these two structures have a reciprocal effect on the collapsing movement, and the complete demolition of the silo is hard to achieve. Therefore, in order to collapse the structure to the forward direction (planned collapsing direction) , a tension failure of the cylindrical shell should be induced to the planned location from the reverse direction (the opposite direction from the planned collapsing direction).

It was thus planned that when columns on the forward direction and partial ring girder of silo No.2 are blasted, the tension failure is created at FL+ $5.^{m}500^{LEV}$ ~ FL+$6.^{m}500^{LEV}$ of the cylindrical shell, while the ring girder and the cone, which are internal structures, would incline to the

Table 1 Formation and size of surrounding structures.

Division	Cement pier	Sand pier	Shore	Barracks
Structure type	Dolphin–type	Solid block–type	Shore (Armor stone)	Concrete block structure
Length	Approaching facility : 186.0 m Connected transfer bridge : 336.8 m	260.0 m	183.2 m	50 m
Width	—	Permanent concrete : 2.5 m	—	17 m

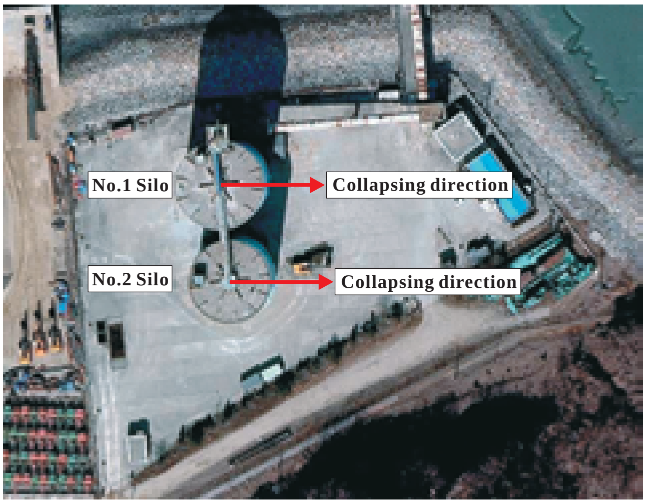


Fig. 4 Expected collapsing direction of the target structure for explosive demolition.

forward direction, and the bending failure would be created at FL+ 11.^{m}000^{LEV} ~ FL+ 12.^{m}000^{LEV} due to the rotating moment of the cylindrical shell.

In addition, since there is a high possibility of a large amount of instantaneous dust and high blast pressure generated to the forward direction at the time of explosive demolition, the collapsing direction was set to the east direction as shown in Fig. 4, by considering the location of the surrounding facilities.

3. Design of explosive demolition and main process

3.1 Selection of blasting blocks

In order to induce the collapse of a cylindrical structure to one direction, blasting blocks should be selected in consideration of the shape, angle and height of blasting area.

In order to prevent kickback to the reversed direction before sufficient rotating moment is created after blasting, a trapezoidal shape of blasting area was selected for this explosive demolition, as shown in Fig. 5, and 255°, which is approximately 70% of the cylindrical silo, was selected for the angle of blasting area in order to increase the initial speed to the vertical direction to the forward. The following formula (1) was used for the height of blasting area.

$$H = B\tan\phi \qquad (1)$$

Where, H = height of blasting area (m), B = maximum distance from the hinge line (m), ϕ = angle of inclination(°). When B = 18.45 m, ϕ = 30° in No.2 silo, H = 10.65 m, and 11.8 m was selected for the height of blasting area so that the cylindrical shell to the forward could clash with the ground directly.

3.2 Examination of environmental effects

3.2.1 Ground vibration

The ground vibration generated at the time of demolishing a structure by blasting can be classified into blasting vibration from the detonation of explosives and impact vibration from the fall of the structure. The formula for predicting blasting vibration generated at the time of demolishing this silo by blasting is as follows (2)[6].

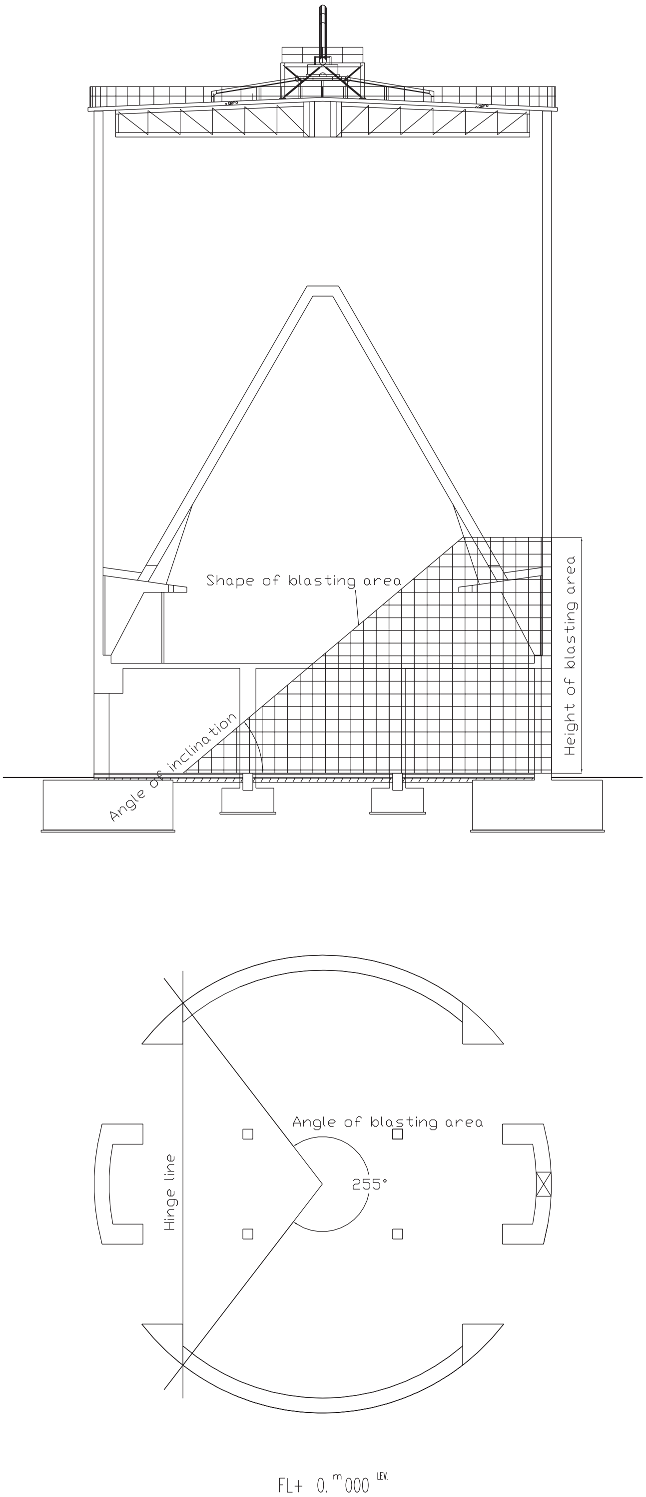


Fig. 5 Blasting blocks according to the shape, angle and height of blasting area (unit : mm).

$$V_b = 32.1\left(\frac{Q^{\frac{1}{3}}}{R}\right)^{1.57} \qquad (2)$$

Where, V_b = velocity of blasting vibration (cm s^{-1}), Q = maximum explosive amount per delay (kg), R = distance (m). Maximum explosive amount per delay is 40 kg, and the estimated velocity of blasting vibration at the military barrack, which is 130 m away, is 0.1 cm s^{-1}.

To estimate impact vibration, the following formula (3) was applied for impulse according to falling impact, and formula (4) was applied to predict impact vibration according to falling impact[6].

$$I = M\sqrt{2gH} \quad (3)$$

$$V_i = 0.08\left(\frac{I^{\frac{1}{3}}}{R}\right)^{1.67} \quad (4)$$

Where, V_i = velocity of impact vibration (cm s^{-1}), I = impact amount (kgm s^{-1}), R = distance (m), M = falling weight (kg), g = acceleration of gravity (m s^{-2}), H = falling height (m) . If the weight of the ring girder, cone, and the upper cylindrical shell is approximately 3,600 t, and the height to the top of the ring girder is 10.3 m, the estimated velocity of impact vibration at the military barrack, which is 130 m away, is 0.46 cm s^{-1}.

Therefore, 0.5 cm s^{-1} was set as the allowable level of ground vibration at this site for blasting, in consideration of blasting vibration and impact vibration.

3.2.2 Flyrock

The following formula (5) and formula (6) were applied in order to examine the effect of flyrock[7].

$$V_c = 20\left(\frac{Q^{\frac{1}{3}}}{W}\right)^{2} \quad (5)$$

$$L = \frac{V_c^2}{g}K \quad (6)$$

Where, V_c = velocity of flyrock (m s^{-1}), L = maximum flyrock distance (m) , Q = explosive amount per hole (kg), W = burden (m), g = acceleration of gravity (m s^{-2}), K = empirical constant. As a result of applying 1.0625 kg for the explosive amount per hole, 0.5 m for the burden and 0.265 for K, the estimated maximum flyrock distance was approximately 187.63 m.

3.3 Pre–weakening process

A pre–weakening process was performed in order to reduce the structural rigidity of the structure and to promote its smooth collapse in the intended direction. Partial breaking of the cylindrical shell and the ring girder was carried out, and a pre–weakening process was carried out according to the designed shape and height of the blasting area. In addition, cutting of steel stairs inside was carried out in consideration of the collapsing direction.1m and 2 m slots were created at $FL+5.^{m}500^{LEV}$ and $FL+11.^{m}000^{LEV}$, respectively, as shown in Fig. 6, in order to induce a tension failure and a bending failure of the cylindrical shell in the reversed direction.

Figure 7 shows the pre–weakening sections and blasting sections at $FL+0.^{m}000^{LEV}$. It was planned for the pre–weakening process to be carried out bisymmetrically from the centerline of the silo, but due to structural stability issues during its execution, the blasting sections were changed to the right side of the shell.

3.4 Test blasting

Test blasting was carried out on the target columns and the cylindrical shell for blasting of silos No.1 and No.2. In consideration of the shape and rebar arrangement of the

Fig. 6 Slots for leading tension failure and bending failure.

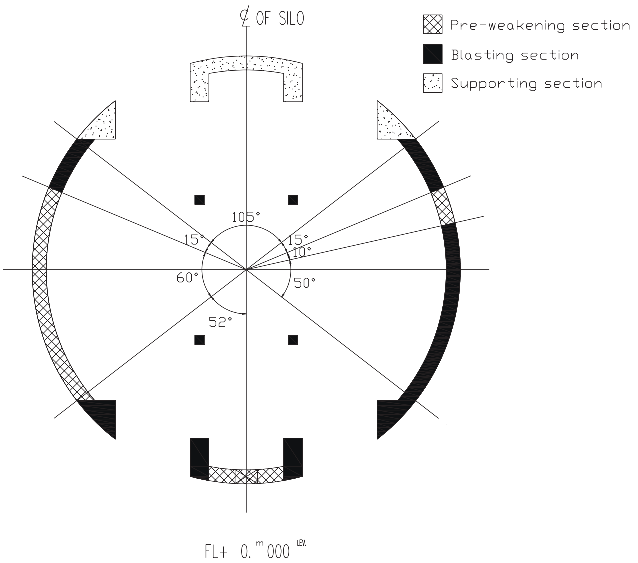


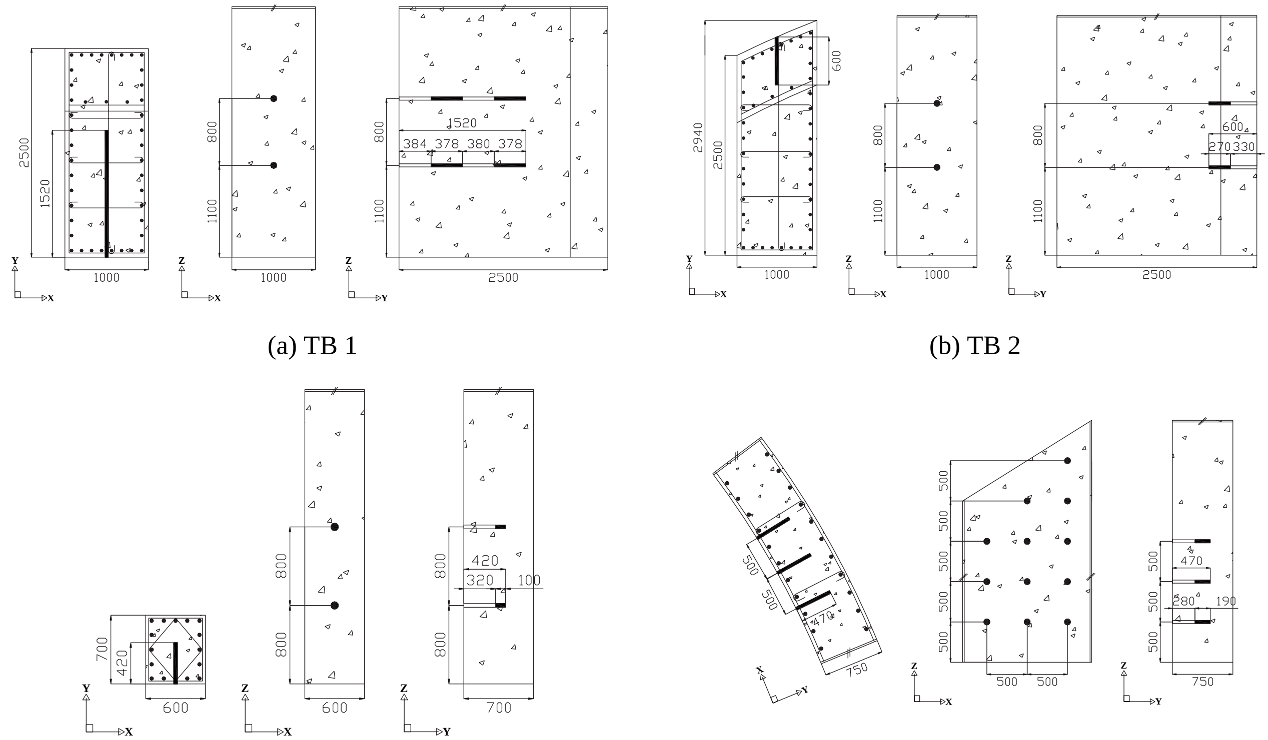
Fig. 7 Pre–weakening sections and blasting sections of silo.

Table 2 Specifications of drilling and the explosive for test blasting.

Division	TB1	TB2	TB3	TB4
Length of borehole (mm)	1,520	600	420	470
Spacing (mm)	800	800	800	500
Number of holes (ea)	2	2	2	12
Amount of explosive per hole (kg)	0.875	0.3125	0.125	0.1875
Specific charge (kg m^{-3})	0.625	0.521	0.372	1.0

target members for blasting, test blasting was carried out for 4 types with different borehole lengths, charge amounts and methods, and Table 2 shows the specifications of this test blasting. Fig. 8 shows the pattern diagram of drilling and loading for each type. TB 1, TB 2 and TB 3 are the test blasting of columns at the time of demolishing silo No.2 by blasting, and TB 4 is the test blasting of the cylindrical shell.

To analyze the result of test blasting, the crushing of concrete and the amount of flyrock were confirmed with the visual observation after test blasting, as shown in Fig. 9. In TB 1, connecting bars on the bottom of columns were arranged, so crushing from lower holes of the columns was



(a) TB 1 (b) TB 2 (c) TB 3 (d) TB 4

Fig. 8 Pattern diagram of drilling and loading for test blasting (unit : mm).

(a) TB1 (b) TB2 (c) TB3 (d) TB4

Fig. 9 Crushing status after test blasting.

unsatisfactory, and the upper holes were over−crushed, creating flyrock. Therefore, the specific charge was increased for the lower holes and decreased for the upper holes in the main blasting design. The overall crushing of TB 3 was satisfactory, but the drilling location was adjusted in the main blasting design by considering the effect of the connecting bar. The overall crushing of TB 2 and TB 4 was satisfactory, so these types were applied to the main blasting design without change.

3.5 Drilling, loading and connecting

By considering the size, shape and fragmentation of the target members for blasting, the drilling patterns were designed in 5 types. The diameter of holes was 38 mm, and the borehole length varied by types, and in the cases of MB 1, MB 2 and MB 5, even the same type was designed with a different borehole length according to the size, shape and fragmentation.

In MB 1, 5 holes in a latticed shape were drilled on the bottom of the column for effect from connecting bar and complete break, and the drilling was carried out on the center for the other parts. Drilling was carried out on both directions because the section of the column is thick and concrete is attached between the internal structure and the cylindrical shell. 2 holes were drilled on the center of the ring girder from the outside for partial fragmentation.

The shape of the columns in MB 2 is a triangle, so the length of the borehole in both side holes is different from the length of the borehole in the central holes. In addition, 2 holes were drilled in 2 rows on the ring girder, and a different length of borehole was applied according to the shape of the ring girder.

The thickness of the cylindrical shell in MB 5 is reduced at FL+ 5.^{m}900^{LEV} from 750 mm to 450 mm, so it was de-

Table 3 Specifications of drilling and the explosive for the main blasting.

Division	Blasting hole No.		Length of borehole (mm)	Spacing (mm)	Number of holes (ea)	Amount of explosive per hole (kg)	Specific charge (kg m^{-3})
MB1	1−1,1−3	Internal	600	400	4	0.225	0.81
		External	1,126		2	0.125	
	1−2	Internal	600	400	1	0.45	0.81
		External	1,188		1	0.25	
	1−4~1−7	Internal	600	800	4	0.75	0.61
		External	1,270		4	0.3125	
	1−8	External	1,000	1,600	1	0.4375	0.41
	1−9	External	1,500	1,600	1	0.625	0.36
MB2	2−A	External	500	800	12	0.25	0.51
	2−B	External	1,000	800	6	0.625	0.51
	2−C−1	External	1,000	1,600	2	0.375	0.24
	2−C−2	External	1,550	1,600	2	0.5625	0.22
MB3	—	—	300	600	2	0.0625	0.42
MB4	—	Internal	470	500	12	0.1875	1.0
MB5	5−1	Internal	470	500	154	0.1875	1.0
	5−2	External	270	400	77	0.0833	1.16

signed in 2 type drilling patterns. The drilling was carried out inside the 750 mm cylindrical shell, but was carried out outside the 450 mm cylindrical shell due to the effect from the ring girder. 343 holes were used in total for blasting the No.2 cement silo, and the total borehole length was 173.89 m.

The explosive used for the explosive demolition of the target structure was Mega MITE I (dynamite) 28 mm, the weight per cartridge was 125 g, and the length per cartridge was 180 mm. The amount of explosive for each type was adjusted according to the fragmentation of the concrete after test blasting, the arrangement of reinforced bars and the shape of the column, and for MB 1 columns, the deck charge was carried out for blasting holes drilled from the inside. The total amount of explosive used for demolishing the No.2 silo by blasting was 71.864 kg. Table 3 shows the specifications of drilling and loading for main blasting, and Fig. 10 shows the pattern diagram of drilling and loading for each type.

Electric detonators were used for the detonation of MB 1, MB 2 and MB 3 demolition, and a 10 g m^{-1} detonating cord was used to detonate MB 4 and MB 5 with electric detonators. 118 electric detonators and 290.6 m in detonating cord were used for demolishing this silo by blasting. The time interval for detonation is as shown in Fig. 11, while MB 4 and MB 5, which are cylindrical shell parts, were detonated initially. Columns and the ring girder were detonated sequentially to the forward direction, and while the angle of blasting area was increased, the cylindrical silo moved to the forward direction.

3.6 Measures for reducing flyrock, impact vibration and dust

To prevent flyrock, non−woven fabric of 150 g m^{-2}, 200 g m^{-2} and #8 galvanized rhombus wire net were installed on the blasting sections for a primary protection, and hex wire mesh was additionally installed around the cylindrical silo for a secondary protection. To reduce the impact vibration, earth banks of 2 m were installed at 20 m and 30 m from the outer wall of the silo to the forward direction, and the earth bank was covered with the non−woven fabric. In addition, to reduce dust generated at the time of demolition of the structure by blasting, watering guns were installed at 6 m intervals to the side of silo. Figure 12 shows the protection, earth banks and watering devices, which were the measures employed to reduce flyrock, impact vibration and dust.

4. The result of explosive demolition

4.1 Collapsing movements

After the blasting sections of No.2 silo were detonated, No.2 silo inclined to the forward direction, and the tension failure began to be created around pre−weakened slots at FL+ 5.^{m}500^{LEV} to the reversed direction of the cylindrical silo after 1.0 s. After 1.4 s, the silo spun to the forward direction based on the support point, and after 2.3 s, the bending failure was created on the slot at FL+ 11.^{m}000^{LEV}. Next, the cylindrical shell on top of the ring girder over FL + 11.^{m}000^{LEV} spun, and the top of the silo crashed into the ground surface. The tension failure and bending failure were created on the pre−weakened slot, and the cement silo collapsed in the planned direction correctly. Figure 13 shows time−sequence pictures of the collapsing movement of cylindrical silo No.2.

4.2 Ground vibration

To measure the ground vibration at the time of the demolition of cement silo No.2 by blasting, measurements were taken from 4 surrounding locations, as shown in Fig. 14. A ground vibration measuring device was installed to-

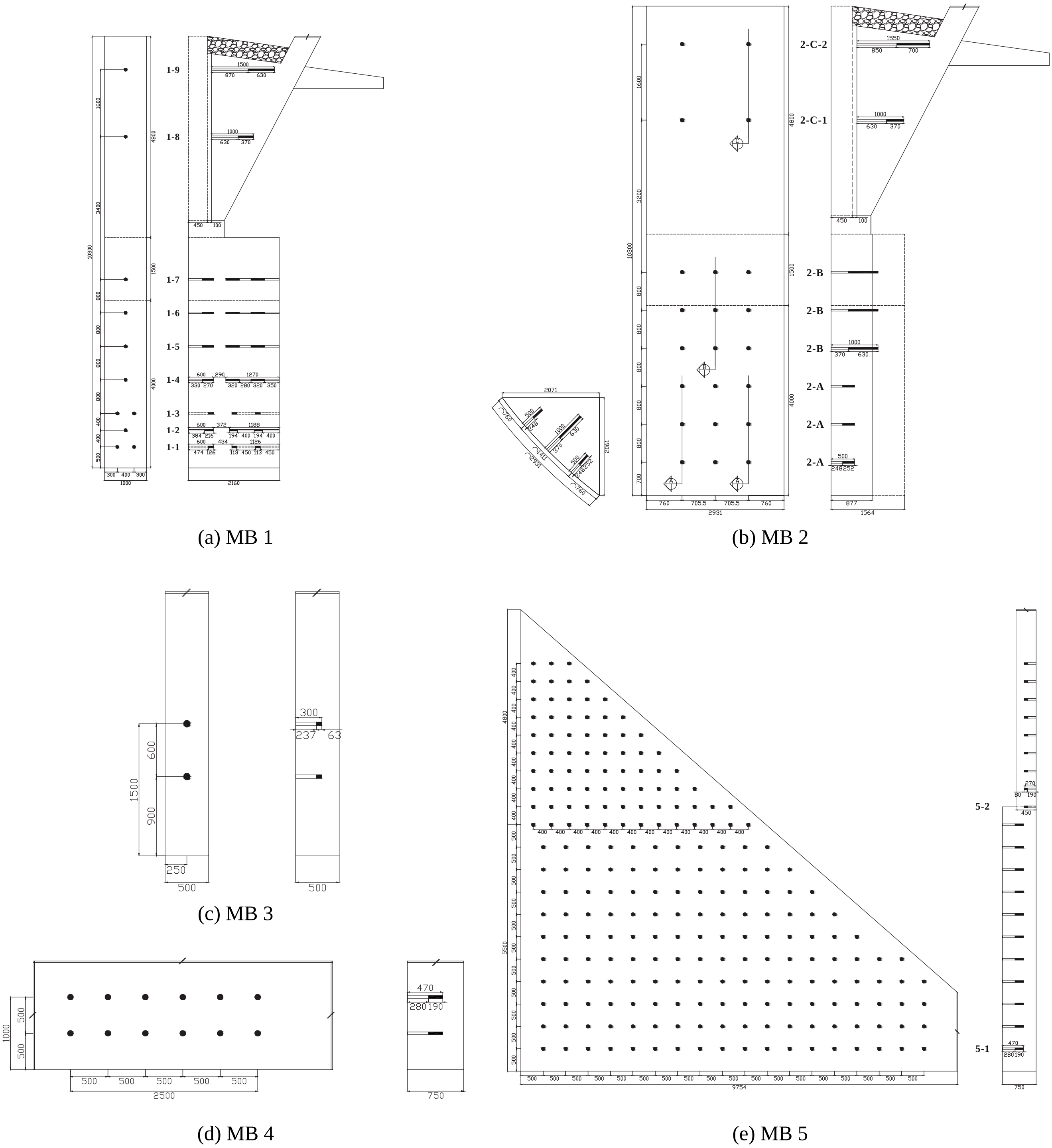


Fig.10 Pattern diagram of holes and the explosive for the main blasting (unit : mm).

ward the center of cement silo No.2. As shown in the Table 4, the ground vibration measured at the military barrack was 0.243 cm s^{-1}, which was higher than the estimated blasting vibration 0.1 cm s^{-1} and smaller than the estimated impact vibration 0.46 cm s^{-1}. The overall ground vibration was measured to be below the allowable values, and due to the characteristics of collapsing movement, the blasting vibration was measured to be higher than the impact vibration. It is considered that this was due to an effect of impact vibration that was reduced by a collapse behavior, an earth bank and a difference of ground condition at each measuring points.

4.3 Dust

A dust measuring device was installed in 3 places where a large amount of dust was expected to be generated at the time of demolishing cement silo No.2 by blasting, and instantaneous dust was measured at one−second intervals from approximately1hour prior to the explosive demolition to the moment after the explosive demolition at which the air is regarded to be stabilized.

These measurements indicated that instantaneous dust at measuring point A and measuring point B located on the forward direction was generated at a level approximately 8 times higher than the instantaneous dust generated at the measuring point C. It is considered that this

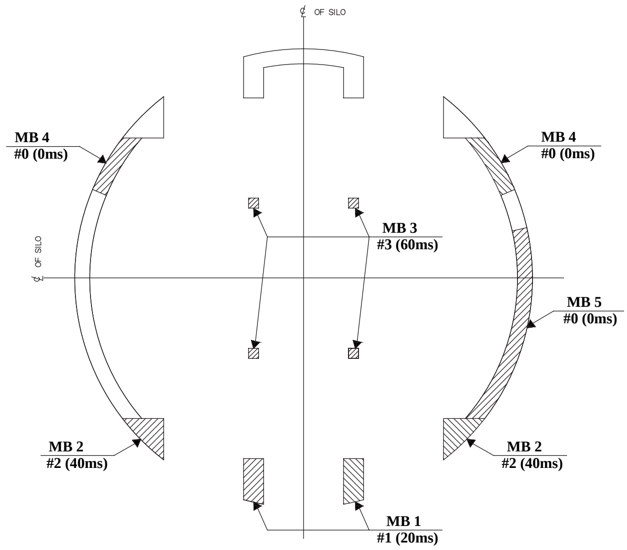


Fig.11 Pattern diagram of detonation.

was due to a large amount of cement dust that remained inside of the silo moving to the forward direction by the blast pressure generated while the silo collapsed. In addition, the water pressure of the watering guns installed for controlling dust was low, so the dust control effect of the watering guns was insignificant. Table 5 shows the weather conditions and locations for dust measurement, and Table 6 shows the results of maximum and average amount of dust measurements.

5. Conclusion

This execution case was a correct and safe demolition of a cement silo that was no longer in use, and the results of this demolition are as follows.

1) As the cement silo had a low height to diameter ratio, and as its internal structure consisting of a cone and a ring girder and its external structure consisting of a cylindrical reinforced concrete shell are separated from each other, it

(a) 1st protection (b) 2nd protection (c) earth bank (d) watering device

Fig.12 Measures for reducing flyrock, impact vibration and dust.

(a)0s (b) 1.0 s (c) 2.0 s

(d) 3.0 s (e) 4.0 s (f) 5.0 s

Fig.13 Time-sequence pictures of the collapsing movement of silo.

Table 4 Results of ground vibration measurements.

Division	PPV ($cm\ s^{-1}$) Tran.	Vert.	Long.	PVS ($cm\ s^{-1}$)	Noise (dB (A))	Distance (m)	Location
#1	0.114	0.254	0.191	0.264	93.2	75	Stock yard
#2	0.114	0.190	0.114	0.192	102.2	110	Sand pier
#3	0.038	0.127	0.025	0.128	95.4	215	Sand pier
#4	0.114	0.241	0.178	0.243	103.4	130	Barracks

Fig.14 Locations of ground vibration measurements.

Table 5 Weather conditions and locations for dust measurement.

Weather conditions	Measurements
Temperature	28.7 °C
Relative humidity	61.2 %
Atmospheric pressure	757.55 mmHg
Wind velocity	2.3~4.8 m s^{-1}

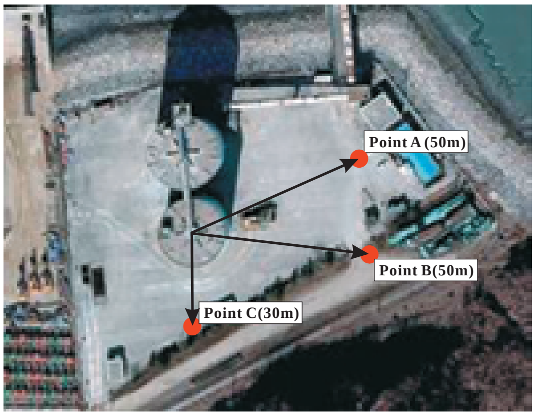
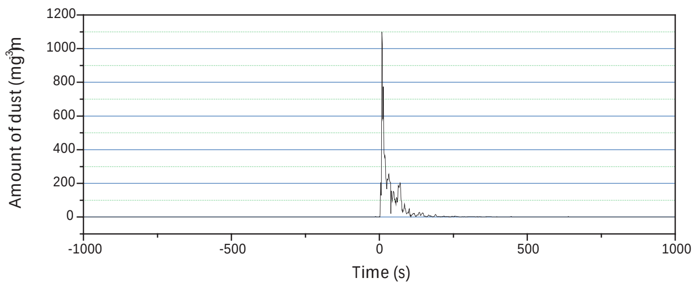
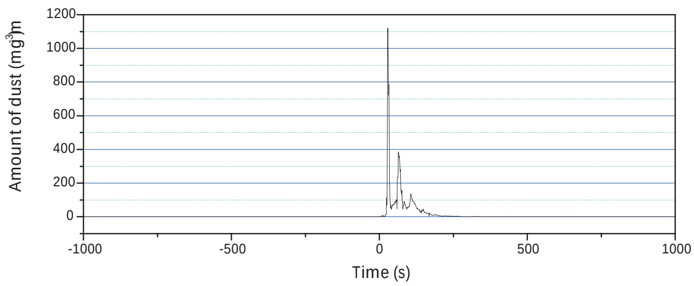
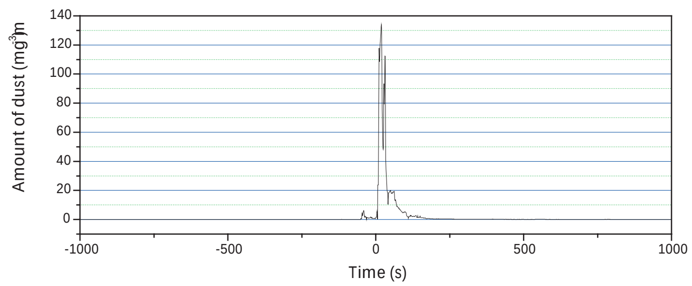


Table 6 Results of dust measurement.

Measuring location	Amount of dust generation	Dust measurement graph by hour
Measuring point A	Max. 1099.3 mg m^{-3} Ave. 5.754 mg m^{-3}	
Measuring point B	Max. 1120.5 mg m^{-3} Ave. 5.472 mg m^{-3}	
Measuring point C	Max. 134.06 mg m^{-3} Ave. 1.042 mg m^{-3}	

is not easy to demolish by blasting, but the demolition of this cement silo by blasting was completed without any damage to the surroundings by applying a pre-weakening process and blasting design that induced the correct collapsing movement of the structure.

2) Due to structural problems during the pre-weakening process, the pre-weakening section on the design had to be changed while executing the pre-weakening process and an analysis of structural stability on the execution process was required.

3) Due to low water pressure, the dust control effect provided by the watering guns was insignificant, and furthermore the efficiency of watering guns was decreased according to their installation and movement, so measures to address these problems are required. In addition, studies to derive appropriate dust controlling devices and methods are required by analyzing the characteristics of dust generation according to the collapsing movement of the structure.

By examining and complementing problems that might occur at the time of demolition of a cylindrical cement silo by blasting, the demand for explosive demolition, as an economic and efficient demolition method that can minimize temporal and spatial environmental effects, will be increased in the future.

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References

1) P. Hoon, S. Chul-Gi, and K. Seung-Kon, EXPLOSIVES & BLASTING (KSEE), 26, 1 (2008).
2) P. Hoon and S. Chul-Gi, TUNNEL & UNDERGROUND SPACE (KSRM), 19, 5 (2009).
3) P. Hoon, J. Seong-Ok, P. Hyong-Ki, K. Nae-Hoi, and S. Chul-Gi, EXPLOSIVES & BLASTING (KSEE), 26, 2 (2008).
4) R. J. Elliott and Woolf, Explosives and Blasting Technique-World conference, pp.397-404 (2000).
5) F. Stangenberg, International symposium Spatial, lattice and tension structures, pp.290-299 (1994).
6) W. Hao, The Asian-Pacific Symposium on Blasting Techniques (APS), pp.273-277 (2007).
7) R. Ji Kai and H. Shan Gwn, Kogyo Kayaku, 51, 5 (1990).