Article

Developments of bulk emulsion explosive in JAPAN and some field tests with it

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Highly improved drilling machines and mucking machines have been used for the tunnel construction in Japan. To have rapid construction, the roles of blasting operation have been growing more important. At the most tunneling of present, packaged explosives have been used for a blasting in Japan. Under this circumstance, a blasting system of ANFO explosive using a loader has been used recently for a tunnel blasting. However, this system has some problems, such as a useless explosive in wet boreholes, bad after fumes and the ammonia gas due to the decomposition of ammonium nitrate in contact with the sprayed concrete in tunnel.

A blasting system using bulk emulsion explosives with loading machine is used practically in overseas. However, it is difficult to introduce this system to Japanese tunneling because of the Japanese Explosives Control Law. The mechanical loading of emulsion explosive is required the development of an emulsion explosive composition and blasting system suitable for tunneling in Japan. Authors have developed a bulk emulsion explosive composition and blasting system to comply with the regulations, and the field blasting tests were carried out to confirm actual operations and blasting effects in three tunnels.

"Emulsion unit" used for explosive loading mainly consists of emulsion tank, pump and hose. We have two units. One is "one-hose type" and the other is "two-hose type". An emulsion pump is a mono progressive cavity pump, which it is called a mono-pump, and the emulsion delivery rate is 25 kilograms per minute.

As a result of the field tests, safety is improved at the face, because the loading time can be reduced. And the cycle time is less than that of packaged products.

1. Introduction

In recent years, the mechanization of explosive loading is requested in the quarry and tunnel construction in Japan. The examination of the long hole blasting have been carried out to extend the length of advance in the tunnel. The blasting system of the ANFO explosive using a loader has been used as the examination of long hole blasting. However, ANFO is poor in waterproof and after fumes are bad in environment of tunnel. Therefore, the use of ANFO sometimes receives restriction.

A blasting system of the type that mixes emulsion and bubble at the site of tunnel construction is used practically in overseas as bulk emulsion explosives [1]. However, it is difficult to introduce this system to Japanese tunneling because of the Japanese Explosives Control Law.

Therefore, a bulk emulsion explosive composition and blasting system that comply with regulations need to be developed for mechanical loading of emulsion explosive.

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2. Development of bulk emulsion explosive

The bulk emulsion explosives in overseas is manufactured an emulsion matrix in manufacturing plants and be loaded to emulsion loading truck. At the face, the bubbles are blended into an emulsion matrix, and it is pumped into each boreholes. Accordingly, storage stability of the emulsion that contained the bubbles is not

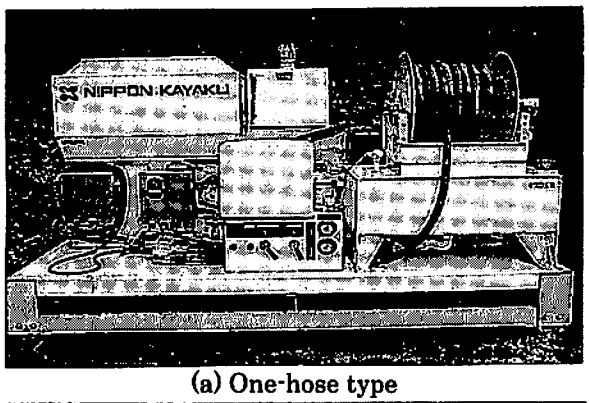
Table 1 Performances of bulk emulsion explosive

Explosives	Bulk emulsion	Packaged emulsion	ANFO
Density ($g \cdot cm^{-3}$)	1.13～1.20	1.15～1.23	0.8～0.9
Waterproof performance	Good	Excellent	None
Cap sensitivity	None	Yes	None
VOD ($m \cdot s^{-1}$)	4800～5300	5800～6000	2500～3000
Ballistic pendulum (mm)	68～74	78～84	45～55

necessary.

On the other hand, the consumption sites have to be distinguished from the production sites in Japan, and it is not possible to do consumption and production simultaneously. When the period from production to consumption is considered, the storage stability of about 1 year is requested with the bulk emulsion explosive that is added the bubble in manufacturing plant.

The principle components of bulk emulsion explosive are ammonium nitrate, water, mineral oil, emulsifier, glass bubbles. The performances of bulk emulsion explosive, ANFO, packaged emulsion explosive are shown in Table 1.



(a) One-hose type

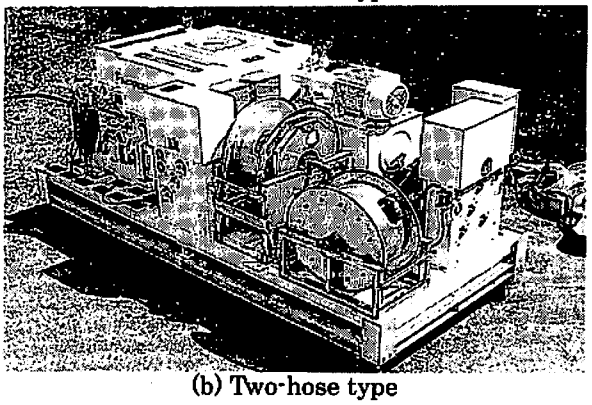

(b) Two-hose type

Fig. 1 Outside appearance of Emulsion unit

3. Emulsion unit

"Emulsion unit" used for explosive loading mainly consists of emulsion tank, pump and hose. "Emulsion unit" used in field tests is shown in Fig.1. Two kinds of emulsion unit are used, one is "one-hose type" and the other is "two-hose type". The "Emulsion unit" was installed on the deck of a 4-tonne truck.

"Emulsion unit" consists of following components and functions:

- An emulsion pump is a mono progressive cavity pump called a mono-pump. The emulsion delivery rate is 25 kilograms per minute.
- An integrated injection pump to introduce the water into the emulsion delivery hose. The water also serves to lubricate the hose and reduce the emulsion pumping pressure.
- Counter to ensure accurate charging quantities in the boreholes.
- Bulk emulsion tank. As for the capacity of tank, "one-hose type" is 300 liter and "two-hose type" is 650 liter.

The operating procedure of "emulsion unit" is as follows.

- The charging quantities are inputted to the control disk.
- The emulsion delivery hose is inserted in the borehole.
- When the start switch is pushed, the emulsion is supplied. The pump stops automatic, after the fixed quantity is delivered.

4. Field test No. 1

The field test No.1 of bulk emulsion explosive was carried out in a tunnel of prefectural road by using "emulsion unit" of " one-hose type". The blasting effect of bulk emulsion explosive and the operation of emulsion unit were inspected mainly

Table 2 Loading situations of field test No.1

Blasting No.	4	5	6	7	8	9
Number of holes	68	68	65	54	61	58
Total charge (kg)	56.3	56.1	54.4	39.2	43.9	41.5
Loading time (min)	45	30	30	21	18	20
Specific charge (kg¥m^{-3})	1.08	1.08	1.05	0.75	0.84	0.80

Table 3 Loading situations of field test No.2

Unit type	One-hose type			Two-hose type		
Blasting No.	1	2	3	4	5	6
Number of holes	60	60	64	73	75	66
Total charge (kg)	62.0	66.8	80.2	184.0	114.6	144.8
Loading time (min)	30	30	35	40	35	25
Loading time per charge 1 kg (sec·kg^{-1})	29	27	26	13	18	10
Hole depth (m)	1.0	1.0	1.0	1.8	1.4	1.8
Rock volume (m^3)	59.4	59.4	59.4	106.9	83.2	106.9
Specific charge (kg·m^{-3})	1.04	1.12	1.35	1.72	1.38	1.35

in this field test.

The 43 m^2 faces were drilled out with 54 to 68 boreholes. These holes were 45mm in diameter and drilled to a depth of 1.2 m. The blasting pattern almost made with the same pattern of packaged explosive that is usually used. The perimeter holes were loaded with packaged emulsion explosives. And the other holes were loaded with bulk emulsion explosives. Blasting was carried out 9 times including the preliminary blasting. The loading situations for 6 times are shown in Table 2.

The quantity of charge and number of boreholes were reduced gradually, while observing each blasting results. The over break of perimeter holes was larger in blasting No.4～6. However, the over break was reduced in blasting No.7～9 that quantity of charge was decreased. The results of blasting were fine.

With respect to operation of emulsion unit, the loading time including the movement between boreholes was 40 seconds at first. However, loading time was shortened in 18 seconds, as it gets used to loading.

5. Field test No. 2

The field test No.2 was carried out in a highway tunnel by using "one-hose type" and "two-hose type". "One-hose type" was used in the field test No.1, and the cycle time was faster than that of packaged products. The operation of "two-hose type" was inspected for the purpose of that reduce further loading time in field test No. 2.

The 59.4m^2 faces were drilled out with 60 to 75 boreholes. These holes were 45mm in diameter and drilled to a length of 1.0 to 1.8m. A bulk emulsion explosive was loaded in all boreholes including perimeter holes. The blasting was carried out dozens time. A part of loading situations are shown in Table 3.

The uncharged part of the hole was cause problems in form of an increased amount of boulders, because this tunnel has a tough rock. So the length of explosives should be greater than 50 % of the borehole. Therefore, the Specific charges were higher than normal blasting.

It was confirmed that the loading time was shortened by using "emulsion unit" of "2-hose type" and be able to economize blasting work. There was not complexity in the work of face, even if two loading hoses are used. Number of the worker needs not to be increased more substantially even in "two-hose type" in comparison with "one-hose type" and safety of face is kept.

6. Field test No. 3

The field test No.3 was carried out in a highway tunnel by using "two-hose type". The application of bulk emulsion for perimeter hole was examined in addition to the inspection of blasting effect and operation of "emulsion unit" in field test No. 3.

Table 4 Loading situations of field test No.3

Blasting No.	12	13	14	15	16
Number of holes	49	45	44	44	49
Total charge (kg)	68.1	87.8	86.3	95.9	88.2
Loading time (min)	28	28	53	15	15
Specific charge ($kg \cdot m^{-3}$)	0.78	0.99	1.00	1.54	1.02
Loading ratio of bulk emulsion (%)*					
Lifter holes	50	50	60	70	35
Other holes	50	50	50	65	55

* : Loading ratio=Explosive length / Borehole length×100

Table 5 Results of cross section measurement

Blasting No.	Ratio of cross-section area (%)*	Type of explosive for perimeter hole	Spacing of perimeter hole
12	111.2	Explosive for smooth blasting	0.9 m
13	108.7	Bulk emulsion	1.0 m
14	113.0	Bulk emulsion	0.6 m loaded in every 1 hole.

* : Ratio of cross-section area=Measured area／Planned area×100

The 49 m^2 faces were drilled out with 44 to 49 boreholes. These holes were 45mm in diameter and drilled to a depth of 1.7 m. Blasting was carried out 16 times and the loading situations for 5 times are shown in Table 4. The operation of "emulsion unit" was fine as the same as the field test No.2.

The total charge decided with the loading ratio (explosive length / borehole length ×100). The loading ratio were changed with regard to the situation of face. The loading ratio of 35 % caused problem in form of increased amount of boulders. The loading ratio of more than 50 % gave good fragmentation with an optimum blasting result.

7. Application of bulk emulsion explosive for the perimeter hole

It is desirable to load explosives for smooth blasting into perimeter holes to decrease overbreak [2]. However, the explosive for smooth blasting need to load by hand work. The combination of the mechanical loading with bulk emulsion and the loading with packaged product decrease the effect of mechanical loading. Therefore, the application of bulk emulsion explosive to perimeter holes was examined.

The following method was adopted to avoid overbreak by overcharge. The blasting by using the explosive for smooth blasting was also carried out for comparison.

- Expansion in 0. 9 m (conventional) to 1.0 m for spacing of perimeter.
- Preparing the blank holes at the center between the perimeter holes to control cracking direction.

(The perimeter holes were drilled in the interval of 0.6 m and bulk emulsion explosive was loaded in every 1 hole.)

The section ratio (%) by section measurement is shown in Table 5. In blasting No.13 and 14, overbreak was controlled as much as the blasting of comparison (blasting No. 12). It is possible to load a bulk emulsion explosive for perimeter holes by using the adopted methods. And devised blasting will minimize the overbreak even in severe geological conditions.

8. Conclusion

- The loading time of bulk emulsion is faster than that of packaged products.
- There is the possibility to reduce the number of borehole may be reduced.
- It is easy to load a bulk emulsion to wet borehole (lifter hole).

- Safety is improved at the face, because the loading time can be reduced.
- The after fumes measurement of NOx and CO was carried out. The after fumes are excellent.
- It is possible to load a bulk emulsion explosive to perimeter hole.

Reference

1) "Blasters Hand book 17th Edition", pp547—560, International Society of Explosives Engineers.
2) Olofsson, Stig O., "Applied Explosives Technology for Construction and Mining", pp178—182 (1998), Applied Explosives Technology.