

**BLAST SYSTEM AND METHOD USING COMBINED PATTERN OF  
ELECTRONIC AND NON-ELECTRIC DETONATORS**

**BACKGROUND OF THE INVENTION**

5   **[0001]** The present invention relates to a blast system and method using a combined pattern of electric and non-electric detonators, which applies electronic detonators and non-electric detonators having a different characteristic and delay time to a single blast excavation  
10 section, thereby improving detonation stability, construction stability, and economic feasibility, and more particularly, to a blast system and method using a combined pattern of electronic and non-electric detonators, which arranges various patterns of electronic detonators and non-  
15 electric detonators in a single blast excavation section divided into a cut region, a stopping region, a contour region, and a floor region in consideration of the characteristics of the electronic and non-electric detonators, the allowable error range of a delay time, and  
20 the utilization purpose, and blasts the electronic detonators and the non-electric detonators at an optimal delayed time , thereby efficiently controlling over-break and vibration and improving an tunnel advance rate and a rock fragmentation rate.

25   **[0002]** In general, tunnel blasting techniques have developed

through the use of change in a drilling and charging method and an initiating method. Since the tunnel blasting techniques are based on the supposition that blasting materials such as explosive materials and ignition system  
5 are utilized, the usability of the tunnel blasting techniques may significantly differ. Furthermore, the use of new blasting materials is very effective in terms of the development and application of blast methods.

**[0003]** In the case of tunnel blasting, the influence of  
10 drilling equipment and dust may be ignored during a blasting operation performed in a tunnel, but noise and vibration caused by explosion of explosive materials may serve as a factor to cause popular complaints. Due to the characteristic of the tunnel blasting, blasting noise  
15 mainly occurs at a tunnel portal, unlike open surface blasting. Recently, as a soundproof facility is installed and operated at the tunnel portal, the popular complaints about blasting noise have been gradually reduced. However, since blast vibration may not be sufficiently controlled  
20 only through the auxiliary facility for noise reduction, much research must be conducted on the blasting techniques such as a drilling method, an initiating method, and a charging method for using a proper charge weight per delay.

**[0004]** In order to build up a more comfortable construction  
25 environment from environment-friendly point of view, the

reduction of noise and vibration must be preceded. Furthermore, it is necessary to control blast vibration and noise which occupy a large part of construction pollution during tunnel excavation. Thus, a mechanical excavation  
5 method may be applied to a section adjacent to a target obstacle, in order to minimize the influence of blast vibration and noise. However, when the mechanical excavation method is applied, the working period may be excessively delayed to thereby decrease constructability  
10 and increase an economic loss. Therefore, there is an urgent demand for a substitute method.

**[0005]** Most of conventional methods for controlling blasting noise during tunnel blasting have been focused on a center cut blast method. For example, method for excavating a  
15 working face by multi-stage blasting method using sequential blasting machine of electric detonation and Pre-Large Hole Boring Machine(hereinafter referred to as "PLHBM") using borehole diameter 200mm over in a single-free-surface tunnel blasting operation have been proposed.  
20 According to the multi-stage blasting method using electric detonators, a delay interval for entire blasting holes of a tunnel is artificially adjusted to control vibration, as illustrated in FIGS. 1 and 2. In the multi-stage blasting method using electric detonators, it is necessary to reduce  
25 a charge weight per delay in terms of vibration control by

the sequential blasting machine. Thus, the multi-stage blasting method using electric detonators may partially overcome the limitation in adjusting delay time of electric detonators, but has low delay time accuracy for  
5 delay elements of the electric detonators and contains an electrical risk at all times. Furthermore, as non-electric detonators are actively used, the use of electric detonators has gradually decreased.

**[0006]** The PLHBM has been developed to control vibration of  
10 a cut portion during a tunnel blasting operation, as illustrated in FIGS. 2A and 2B. According to this technique, a cut portion is not formed through a blasting operation, but an uncharged hole having a predetermined size is drilled to build an artificial two-free-surface  
15 condition. Then, the magnitude of vibration generated during a one-free-surface blasting operation may be minimized.

**[0007]** However, this method requires separate dedicated excavation equipment to perform a large-diameter horizontal  
20 boring operation. Furthermore, an excessive amount of time is required to carry, install, and dismantle the excavation equipment, and other operations cannot be simultaneously performed while the excavation equipment is operated. Thus, when this method is applied, the working period required  
25 for actual operation inevitably increases. In particular,

vibration and dust may occur during the large-diameter horizontal boring operation, and a construction cost per meter is relatively high.

**[0008]** In general, blast vibration tends to increase when  
5 the condition (number and scale) of free surfaces is poor or confining pressure is high. Under a confined condition within underground rock, such as a tunnel, the peak value of vibration waveform generally occurs at a blasting step for a cut region in most cases. Since the center-cut  
10 blasting operation is performed to form an additional free surface under the initial single-free-surface condition, the condition of the free surfaces is poor, and the surrounding confining pressure is relatively larger than in an excavation region. Therefore, a charge weight per  $\text{m}^3$  and  
15 a specific drilling depth are larger than in other regions (stopping region, floor region, and contour region). Thus, the cut region requires a larger number of drilled holes, a larger amount of charge, and a larger number of detonators than the other regions. In particular, a precise delay  
20 interval is required for vibration control such that a peak value does not occur due to waveform superposition, while the charge weight per delay and the number of simultaneous blasting holes are minimized.

**[0009]** The scale and number of free surfaces have close  
25 correlation with blasting efficiency. In particular, the

correlation becomes obvious during an excavation operation for underground space in which a degree of rock restraint is higher than in the open air.

**[0010]** When a blasting operation for the cut region is successively performed, rocks may be smoothly broken and discharged. Then, blasting operations for the other regions may be smoothly performed. Thus, the blasting operation for the cut region is very important in terms of blasting efficiency. Furthermore, since a relatively high degree of rock restraint is applied to the region where the initial blasting operation is performed, a peak value of vibration generally occurs in the cut region. Thus, a precise delay time is required for the cut region, in order to improve the advance rate and control vibration. For this delay time, an initiation system having a super - precise delay time needs to be applied to the cut region.

**[0011]** The electronic detonator initiation system is an initiation system which has been developed in the early 1990s, and includes an IC chip set board as a delay element to realize a super-precise delay time of 1ms step.

**[0012]** General detonators (electric detonator or non-electric detonator) use special explosive materials (e.g. PETN, RDX etc.) as a delay element, in order to apply a delay time based on the number of delays of each detonator. The special explosive materials have a direct effect on the

delay time precision, depending on a minute physical/chemical change. On the other hand, since the electronic detonator is controlled by a programmed IC chip set board, the electronic detonator has a degree of precision which is about 1,000 times greater than general detonators. Furthermore, general detonators are collectively manufactured to have a designated delay time for the number of delays of each detonator. In the electronic detonator, however, an arbitrary delay time may be set in the range of 1ms to 30,000ms by the 1ms.

**[0013]** Recently, the use of blasting techniques using the characteristics of the electronic detonator has been expanded in consideration of constructability and economical feasibility as well as environmental friendliness.

**[0014]** The reason that the use of electronic detonators must be expanded may be explained as follows, in terms of the environmental friendliness and the constructability and economical feasibility.

**[0015]** In terms of the environmental friendliness, as blasting operations for land development are performed under and around the urban area, a large number of public complaints may be caused from environmental pollution such as vibration and noise of the blasting operations. Main factors of blasting noise and vibration may include

inaccuracy of detonator delay time and a lack of interval number.

**[0016]** Furthermore, the constructability and economical feasibility of a tunnel blasting operation may be  
5 determined by an advance rate, a fragmentation rate, a damage area of rock around an excavation line. The factors having an influence on the advance rate, the fragmentation rate, the damage zone of rock mass around an excavation line may include an amount of explosive materials, a  
10 drilling space, a burden, a powder factor, a drilling precision, and a detonator delay time. That is, when the detonator delay time is inaccurate, the advance rate and the fragmentation rate may be decreased. In this case, since a secondary fragmentation operation is requested, the  
15 constructability and economical feasibility may be degraded. In particular, an LP (Long Period) detonator is generally used for contour holes, and has an error range of several tens to hundreds ms. When the detonator delay time is inaccurate, a simultaneous blasting effect within same  
20 interval number may be reduced, and the damage of surrounding rocks may be increased. Then, since amount of used reinforcement support members must be increased, the constructability and economical feasibility may be degraded.

**[0017]** Thus, in order to improve the environmental  
25 friendliness and the constructability and economical

feasibility, electronic detonators having a super-precise delay time may be used in entire working places. However, the electronic detonators are expensive. Thus, when the electronic detonators are applied to the entire working  
5 places, the economic feasibility may slightly decrease, compared to the cost reduced through the blasting efficiency.

**[0018]** Furthermore, when the electronic detonators are applied to the entire working places during a tunnel  
10 excavation cycle, a charging time is 1.5 to 2 times longer than when general detonators are applied. Thus, the entire cycle time inevitably increases. The tunnel excavation cycle may include a series of tunnel excavation processes (face mapping → survey and marking → drilling → charging  
15 → blasting → ventilation → mucking → support member reinforcement).

**[0019]** In order to overcome the above-described problems, research has been actively conducted on a combined initiation system using various patterns of electric  
20 detonators, non-electric detonators, and electronic detonators which have different characteristics.

**[0020]** An initiation system using a combination of electric and non-electric detonators or a combination of electric and electronic detonators has a low technical affinity  
25 between the respective detonators, contains a risk of cut-

off or misfire, and has no economical feasibility.

**[0021]** The present applicant has proposed a blast system and method using a combination of electronic and non-electric detonators (Korean Patent Laid-Open Publication No. 10-0665880) as a measure for improving the constructability and economical feasibility of an excavation method, and spread the blast system and method to various sites.

**[0022]** As illustrated in FIGS. 3A and 3B, the blast system and method is characterized in that a blast zone is divided into a cut region 100, a stopping region 120, a contour region 130, and a floor region 140, electronic detonators are arranged in the cut region 100, non-electric detonators are arranged in the stopping region 120, the floor region 140, and the contour region 130 through a leading wire, and the electronic detonators 201 and the non-electric detonators 202 are blasted with a delay time.

**[0023]** Reference numeral 203 represents a 0-ms electronic detonator, and reference numeral 204 represents an electronic-detonator blasting machine.

**[0024]** According to the above-described blast system and method, the electronic detonators capable of performing a blasting operation at a precise delay time are used in the cut region only where the confinement of rock mass is the largest, during a tunnel blasting operation. Thus, an independent waveform may be implemented for each blasting

hole of the cut region, and a mutual vibration interference effect may be used to reduce the vibration level of the blasting operation. Furthermore, the advance rate and the fragmentation rate may be improved through a free-surface  
5 formation effect which is sequentially expanded. Furthermore, the blast system and method has better blasting efficiency than a blast system and method using general detonators (electric and non-electric detonators) across entire working places, and exhibits more excellent  
10 constructability and economical feasibility than a blast system and method using electronic detonators across entire working.

**[0025]** In the above-described blast system and method, however, the non-electric detonators arranged in the  
15 contour region have low time precision and a limited delay time. Thus, it is relatively difficult to control over-break/under-break occurring on a final excavation fracture surface. Thus, the occurrence rate of public constraints may continuously increase in an area adjacent to an urban  
20 area or obstacle, additional reinforcement support members may be used due to the damage of surrounding rocks, and additional processes may be required due to the reduction in environment stability, such as the increase of fragmented rocks and falling rocks. Then, the working  
25 period may be delayed, and the construction cost may be

increased.

**[0026]** In particular, the detonating system using a combined pattern of electronic detonators and non-electric detonators needs to be deeply researched, in order to  
5 expand applicability and secure the constructability and economic feasibility. That is, various applied patterns need to be researched and verified.

#### **SUMMARY OF THE INVENTION**

10 **[0027]** An embodiment of the present invention is directed to a blast system and method using a combined pattern of electronic and non-electric detonators, which arranges various patterns of electronic detonators and non-electric detonators in a single blast excavation section divided  
15 into a cut region, a stopping region, a contour region, and a floor region according to the utilization purpose, and blasts the electronic detonators and the non-electric detonators at an optimal delayed time , thereby efficiently controlling over-break and improving an advance rate and a  
20 fragmentation rate.

**[0028]** Another embodiment of the present invention is directed to a blast system and method using a combined pattern of electronic and non-electric detonators, which sets a proper delay time in consideration of a delay time  
25 for each of electronic detonators and non-electric

detonators which are arranged in a single blast excavation section and an error range of the detonator, such that detonation operations of the respective regions are sequentially performed to prevent cut-off or misfire, thereby improving construction stability and economic feasibility.

**[0029]** In accordance with an embodiment of the present invention, a blast system using a combined pattern of electronic and non-electric detonators includes: a blast excavation area divided into a cut region formed in the center of the excavation area, a stopping region formed around the cut region, a contour region formed at the outermost part of the stopping region, and a floor region formed at the bottom of the cut region; electronic detonators arranged in the cut region and the contour region of the blast excavation area and connected through a leading wire; non-electric detonators arranged in the stopping region and the floor region of the blast excavation area and connected through a leading wire; and an electronic-detonator blasting machine for blasting the electronic detonators and the non-electric detonators with a delay time. The cut region may include a horizontal cut pattern in which one or more large-diameter uncharged holes having a diameter of 3 inch (Ø76mm) or more are arranged.

**[0030]** In the blast system, electronic detonators may be

additionally disposed in a part of a section in which a problem is likely to occur, thereby further efficiently reducing blasting vibration level.

**[0031]** In accordance with another embodiment of the present invention, a blast method using a combined pattern of electronic detonators and non-electric detonators may include: a first step of dividing a blast excavation area into a cut region, a stopping region, a contour region, and a floor region according to a rock condition of ground to be excavated; a second step of arranging electronic detonators in the cut region and the contour region, arranging non-electric detonators in the stopping region and the floor region, and connecting the electronic detonators and the non-electric detonators through leading wires; a third step of setting a delay time in consideration of a detonator delay time for each hole in the divided regions of the blast excavation area and an error range of the non-electric detonators; and a fourth step of performing detonation according to the following sequence: the cut region, the stopping region, the floor region, and the contour region, with the delay time of the third step.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0032]** FIG. 1 is a front view for explaining a conventional

multi-stage blasting method using electric detonators in single-free-surface tunnel blast.

**[0033]** FIG. 2 is a cross-sectional view taken along line A-A of FIG. 1.

5 **[0034]** FIG. 3 is a front view for explaining a conventional PLHBM (Pre-Large Horizontal Borehole Method).

**[0035]** FIG. 4 is a cross-sectional view taken along line A-A of FIG. 3.

**[0036]** FIG. 5 is a conceptual view of blast system using a  
10 combined pattern of electronic and non-electric detonators which is disposed the electronic detonators in a cut region only.

**[0037]** FIG. 6 is a connection drawing of combined pattern of electronic and non-electric detonators.

15 **[0038]** FIG. 7 is a conceptual view illustrating a combined pattern of electronic and non-electric detonators in accordance with an embodiment of the present invention, illustrating a blast sequence.

**[0039]** FIG. 8 is a diagram illustrating a first pattern of a  
20 blast system using a combined pattern of electronic and non-electric detonators in accordance with the embodiment of the present invention.

**[0040]** FIG. 9 is a diagram illustrating a standard drilling pattern of the blast system using a combined pattern of  
25 electronic and non-electric detonators in accordance with

the embodiment of the present invention.

**[0041]** FIG. 10 is a cross-sectional view taken along line A-A of FIG. 9.

**[0042]** FIG. 11 is a diagram illustrating a second pattern of the blast system using a combined pattern of electronic  
5 detonators and non-electric detonators in accordance with the embodiment of the present invention.

**[0043]** FIG. 12 is a diagram illustrating the trial blasting location and measure points of blast vibration.

10 **[0044]** FIG. 13 is a diagram illustrating a non-electric blasting pattern in accordance with a comparative embodiment of the present invention.

**[0045]** FIG. 14 is a cross-sectional view taken along line A-A of FIG. 13.

15 **[0046]** FIG. 15 is a nomogram illustrating correlation between precision and standard deviation range of detonators.

**[0047]** FIG. 16 is a block connection diagram of a non-electric blast pattern.

20 **[0048]** FIG. 17 is a waveform graph of data sampling for auto-correlation analysis of general blast method using non-electric detonators.

**[0049]** FIG. 18 is a waveform graph of data sampling for auto-correlation analysis of the blast method in accordance  
25 with the embodiment of the present invention.

**[0050]** FIG. 19 is a graph illustrating results of the vibration regression analysis using a square-root scaled distance in the general blast method and the blast method in accordance with the embodiment of the present invention.

5 **[0051]** FIG. 20 is a distribution chart of G-values in the blast method in accordance with the embodiment of the present invention.

**[0052]** FIG. 21 is a distribution chart of G-values in the general blast method using the non-electric detonators.

10 **[0053]** FIG. 22 is a diagram illustrating a trial blast pattern for evaluating over-break in the blast method in accordance with the embodiment of the present invention.

**[0054]** FIG. 23 is a cross-sectional view taken along line A-A of FIG. 22.

15 **[0055]** FIG. 24 is a diagram illustrating a trial blast pattern for evaluating over-break in the general blast method using the non-electric detonators.

**[0056]** FIG. 25 is a cross-sectional view taken along line A-A of FIG. 24.

20 **[0057]** FIG. 26 is a graph illustrating seismic survey results for the general blast method and the blast method in accordance with the embodiment of the present invention at a side wall area of tunnel.

**[0058]** FIG. 27 is a conceptual view illustrating a combined  
25 blast pattern of electronic and non-electric detonators in

open pit.

#### **DESCRIPTION OF SPECIFIC EMBODIMENTS**

**[0059]** Exemplary embodiments of the present invention will  
5 be described below in more detail with reference to FIGS. 7  
to 27. The present invention may, however, be embodied in  
different forms and should not be constructed as limited to  
the embodiments set forth herein. Rather, these  
embodiments are provided so that this disclosure will be  
10 thorough and complete, and will fully convey the scope of  
the present invention to those skilled in the art.  
Throughout the disclosure, like reference numerals refer to  
like parts throughout the various figures and embodiments  
of the present invention.

15 **[0060]** A blast system and method using a combined pattern of  
electronic and non-electric detonators in accordance with  
an embodiment of the present invention are implemented to  
minimize blast vibration level and over-break and increase  
an advance rate.

20 **[0061]** FIG. 7 is a conceptual view illustrating a combined  
pattern of electronic and non-electric detonators in  
accordance with an embodiment of the present invention,  
illustrating a blast sequence. FIG. 8 is a diagram  
illustrating a first pattern of a blast system using a  
25 combined pattern of electronic and non-electric detonators

in accordance with the embodiment of the present invention. FIG. 9 is a diagram illustrating a standard drilling pattern of the blast system using a combined pattern of electronic and non-electric detonators in accordance with the embodiment of the present invention, and FIG. 10 is a cross-sectional view taken along line A-A of FIG. 9.

**[0062]** As illustrated in the drawings, the blast system using a combined pattern of electronic and non-electric detonators in accordance with the embodiment of the present invention includes a blast excavation area 2, electronic detonators 4, non-electric detonators 8, and an electronic-detonator blasting machine 12. The blast excavation area 2 is divided into a cut region 10 formed in the center of the excavation surface, a stopping region 20 formed around the cut region 10, a contour region 30 formed at the outermost of the stopping region 20, and a floor region 40 formed at the bottom of the cut region 10. The electronic detonators 4 are disposed in the cut region 10 and the contour region 30 of the blast excavation area 2, and connected through a leading wire 6. The non-electric detonators 8 are disposed in the stopping region 20 and the floor region 40 of the blast excavation area 2, and connected through a leading wire 7. The electronic-detonator blasting machine 12 serves to blast the electronic detonators 4 and the non-electric detonators 8 with a delay time.

**[0063]** As illustrated in FIG. 10, the cut region 10 may include a horizontal cut pattern in which one or more uncharged holes 14 having a large diameter of 3 inch ( $\varnothing 76\text{mm}$ ) or more are arranged, in order to improve blasting efficiency and provide a blast vibration control effect.

**[0064]** Furthermore, the cut region 10 may include an angle-cut pattern based on a V-cut blasting pattern, instead of the horizontal cut pattern. The angle-cut pattern is not suitable for vibration control, because the advance rate can be maximized only when simultaneous blasting is performed on left and right symmetrical holes lines. However, an operation for excavating a small-section tunnel (electric power hole, communication hole, waterway tunnel, vertical shaft or the like) is performed through a manual drilling operation. At this time, the angle-cut pattern may be mainly used. When the angle-cut pattern is reflected into the cut region, simultaneous blasting must be performed on hole lines which are symmetrical with each other. Thus, a precise delay time is required.

**[0065]** FIG. 15 is a schematic view illustrating precision based on standard deviation between the neighboring numbers of delays, indicating that a risk of overlapping between the neighboring numbers of delays increases when the standard deviation increases.

**[0066]** In the case of MSD (Milli-Second Detonators) as

general detonators (electric and non-electric detonators),  
an error range of  $\pm 5 \sim 10$ ms is allowed at the number of  
delays at which a time interval of  $20 \sim 25$ ms is required, and  
a standard deviation of  $\pm 50 \sim 100$ ms for each delay is allowed  
5 at the number of delays for LPD (Long Period Detonators),  
at which a time interval of  $100 \sim 200$ ms is required. On the  
other hand, the electronic detonator 4 shows a standard  
deviation of 0.2ms or less, and has a super-precise delayed  
time which does not deviate from an allowable error range  
10 of 0.1 to 0.2ms. In particular, general detonators have  
such a tendency that the standard deviation for each delay  
increases toward the rear stage of LP detonators, but the  
electronic detonator 4 has a uniform delay time precision  
within an allowable error range. Considering that the rear  
15 stage of LP detonators is applied to the outermost part of  
the tunnel, it is possible to expect that the delay time  
precision is closely related to the over-break of a target  
excavation line and the damage of surrounding rock.

**[0067]** In the present embodiment, the electronic detonators  
20 4 are disposed in the contour region 30 as well as the cut  
region 10 at which the confinement of the ground is the  
strongest. At this time, a delay time for each hole of the  
cut region 10 is set in the range of 15 to 50ms.

**[0068]** Thus, when the electronic detonators 4 disposed in  
25 the cut region 10 are detonated, two free surfaces are

formed by the horizontal cut pattern forming the large-diameter uncharged holes at the same time. Thus, blasting vibration may be minimized, and the advance rate and the fragmentation rate may be improved. Furthermore, since the  
5 detonation of the electronic detonators 4 disposed in the contour region 30 is performed at a precise delay time, a smooth surface may be formed. Therefore, an additional amount of shotcrete and concrete may be reduced, and the damage of surrounding rock may be minimized.

10 **[0069]** Furthermore, the electronic detonators may be disposed in the cut region 10 so as to secure the precision of time error. Then, the blasting operation may be smoothly performed according to the scheduled blast sequence. Furthermore, as the electronic detonators are  
15 also disposed in the outermost contour region serving as a blast zone to provide a final excavation surface, the delay time precision may be provided to secure a smooth surface and reduce the damage of parent rock.

**[0070]** By the way, the following [table 1] is showing  
20 an allowable production standard of general detonators (Swedish standard).

| Delay No. | Delay time (ms) | Interval (+ms) | Accepted scatter Dyno Nobel Standard( $\pm$ ms) | Accepted scatter Swedish Standard( $\pm$ ms) |
|-----------|-----------------|----------------|-------------------------------------------------|----------------------------------------------|
| 0         | 25              | 75             | 5                                               | 10                                           |
| 1-5       | 100-500         | 100            | 5                                               | 50                                           |
| 6-12      | 600-1200        | 100            | 8                                               | 50                                           |
| 14-20     | 1400-2000       | 200            | 50                                              | 50                                           |
| 25-60     | 2500-6000       | 500            | 8                                               | 250                                          |

**[0071]** As illustrated in FIG. 9, the stopping region 20 in accordance with the embodiment of the present invention may be divided into six regions ① to ⑥ over the cut region and in the left and right side of the cut region. At this time, an external delay time may be set for each region, and the six regions may be blasted according to the following sequence: the central regions are first blasted and the left and right regions are then alternately blasted.

**[0072]** Then, the blast method using a combined pattern of electronic and non-electric detonators in accordance with the embodiment of the present invention will be described in detail.

**[0073]** First, a blast excavation area 2 is divided into four regions according to the rock condition of ground to be excavated. That is, the blast excavation area 2 is divided into a cut region 10 formed in the center of a tunnel, a stopping region 20 expanded around the cut region 10, a

contour region 30 formed at the outermost of the tunnel,  
and a floor region 40 formed at the bottom of the cut  
region 10. After the blast excavation area is divided,  
drilling is performed for each region. At this time, a  
5 horizontal cut pattern is formed in the center of the cut  
region 10. The horizontal cut pattern includes one or more  
large-diameter uncharged holes 14 for suppressing blasting  
vibration.

**[0074]** Furthermore, electronic detonators 4 are arranged in  
10 the cut region 10 and the contour region 30, and non-  
electric detonators 8 are arranged in the stopping region  
20 and the floor region 40. Then, the electronic  
detonators 4 and the non-electric detonators 8 are  
connected through leading wires 6 and 7.

15 **[0075]** Furthermore, a delay time is reflected in  
consideration of a detonator delay time for each hole of  
the cut region 10 and the contour region 30 in which the  
electronic detonators 4 are disposed, a detonator delay  
time for each hole of the stopping region 20 and the floor  
20 region 40 in which the non-electric detonators 8 are  
disposed, and an error range of the detonators. The  
blasting operation is performed according to the following  
sequence: the cut region, the stopping region, the floor  
region, and the contour region. As a proper delay time is  
25 reflected into the electronic detonators 4 and the non-

electric detonators 8, the detonators of the respective regions are sequentially detonated. Thus, it is possible to prevent the occurrence of cut-off or misfire.

**[0076]** The detonator delay time for each hole of the cut  
5 region and the contour region in which the electronic  
detonators are disposed may be applied as follows. First,  
in the case of the cut region, the detonator delay time may  
be set in consideration of the strength of rock, the  
drilling depth, and space. At this time, the detonator  
10 delay time may be set to 10~20ms for hard rock (high  
strength), 15~25ms for normal rock (medium strength), and  
25~35ms for soft rock (low strength). Furthermore, the  
detonator delay time may be set in consideration of a  
discharge speed of blasted rock depending on the drilling  
15 depth and an additional delay time of  $\pm 5\sim 10$ ms. In  
particular, a delay time for a section which is extremely  
sensitive to the occurrence of vibration may be set through  
the analysis of waveforms obtained by performing small-  
scale test blasting. In the cut region, a delay time is  
20 set in the range of 10 to 50ms for each hole. In the  
contour region, simultaneous blast may be performed to form  
a smooth surface and minimize a rock damage area. However,  
in order to control a charge weight per delay, the roof and  
the left and right walls may be divided into 2~3 regions in  
25 such a range that does not exceed an allowable charge

weight per delay. Then, simultaneous blast may be performed for each group or a predetermined delay time of about 10ms may be applied to alternately perform delay blast for the left and right sides. In the stopping region and the floor region in which non-electric detonators are disposed, a delay time is set on the basis of a final detonation time of the cut region in which the electronic detonators are disposed. Since MSD (Milli-Second detonators) of the non-electric detonators are completely consumed in the cut region where the electronic detonators are disposed, LPD (Long Period Detonators) of the non-electric detonators are generally utilized. In the stopping region, a delay time of a non-electric detonator which is first detonated must be set in consideration of the final delay time of the cut region and a time error of the non-electric detonator. For example, when the final delay time of the cut region is 1,000ms, the first delay time of the stopping region in which non-electric detonators are disposed may be set to a delay time of 1,200~1,500ms obtained by adding 200~500ms. After the blasting operation for the stopping region, a blasting operation for the floor region is sequentially performed through the non-electric detonators. Then, when the detonation of the contour region having the electronic detonators arranged therein starts, a delay time of 300ms

to 1,000ms between the regions is required in consideration of a delay time of a non-electric detonator which is finally detonated in the floor region and an allowable error of the non-electric detonator. This is because the time error range is expanded toward the latter part of the LPD (Long Period Detonators) in the non-electric detonators.

**[0077]** During the tunnel blasting in accordance with the embodiment of the present invention, a section of which the advance rate and the fragmentation rate are low may occur due to the characteristic of surrounding rocks. Although bench blasting is performed on two free surfaces, the tunnel blasting starts from one free surface and then forms two free surfaces while the tunnel blasting is performed. During the blasting operation for the cut region 10, which develops from the one-free-surface condition to the second-free-surface condition, the confinement of the ground may be most strongly applied, and the blasting operation has an effect on the successive blast regions. Thus, as the electronic detonators 4 having a super-precise delayed time are applied to the blasting operation for the cut region 10 and the contour region 30 as illustrated in FIG. 9, accurate simultaneous blast may be performed to thereby increase the advance rate and the fragmentation rate and reduce vibration and over-break.

**[0078]** FIG. 11 is a diagram illustrating a second pattern of

the blast system using a combined pattern of electronic detonators and non-electric detonators in accordance with the embodiment of the present invention, illustrating a pattern in which electronic detonators are arranged in the cut region 10 and the contour region 30 and second electronic detonators 5 are additionally installed in a part of the stopping region 20.

**[0079]** The second electronic detonator 5 serves to expand the cut region, and is connected to a bunch connector 11 which branches a leaning wire 7 for non-electric detonators of the stopping region 20. Furthermore, each of the non-electric detonators disposed in the stopping region 20 has a surface delay time of 0ms, 17ms, 25ms, or 42ms.

**[0080]** When a precise blasting operation is required for an open pit adjacent to an urban area or obstacle, a combined pattern of electronic detonators and non-electric detonators may be effectively applied according to the above-described operation sequence, in order to control vibration, increase rock fragmentation efficiency, and form a smooth surface. In the case of the open pit blasting, a cut region is not needed because two or more free surfaces are already secured in most cases. The open pit blasting may be designed so as to efficiently expand the secured free surfaces. The region is roughly divided into a primary stopping region 60, a secondary stopping region 70,

an excavation line region 80. Then, electronic detonators are arranged in the primary stopping region 60 and the excavation line region 80, non-electric detonators are arranged in the secondary stopping region 70, and the  
5 electronic detonators and the non-electric detonators are connected through a leading wire. Depending on the rock characteristic and the drilling depth, a different delay time may be reflected. That is, a delay time of a detonator in each hole may be set to 10~50ms and a surface  
10 delay time may be set to 100~500ms, in order to induce a clear independent waveform depending on delay blast for each hole.

**[0081]** Then, the detonation is performed according to the following sequence: the primary stopping region, the  
15 secondary stopping region, and the excavation line region, with a delay time.

**[0082]** Hereafter, test results of the blast system using a combined pattern of electronic and non-electric detonators in accordance with the embodiment of the present invention  
20 will be described in comparison with a non-electric blast system.

**[0083]** The evaluation items of the blast system in accordance with the embodiment of the present invention may include vibration in terms of environment friendliness and  
25 an advance rate, a fragmentation rate, over-break, and a

rock damage zone in terms of constructability and economical feasibility.

**[0084]** The vibration evaluation was performed at a tunnel between SU-SOE and PYOUNG-TAEK in Korea. At this site, the  
5 blast method in accordance with the embodiment of the present invention (hereafter, referred to as a new blast method) and the non-electric blast method (hereafter, referred to as a general blast method) were selected, and trial blasting was performed two times for each method. At  
10 each blasting operation, 10 vibration measurement instruments were used to measure vibration.

**[0085]** FIG. 12 is a diagram illustrating trial blasting location and measurement points for vibration checking.

**[0086]** The new blast method was tested according to the  
15 blasting patterns illustrated in FIGS. 9, 10 and 11, and a blasting pattern of the general blast method is illustrated in FIGS. 13 and 16. FIGS. 13 and 14 are diagrams illustrating a non-electric blasting pattern and a cross-sectional view taken along line A-A, respectively. FIG. 16  
20 is a diagram illustrating block connection of the non-electric blasting pattern.

**[0087]** The vibration evaluation in terms of the environment friendliness may be divided into an auto-correlation function for checking a detonation delay time, regression  
25 analysis for analyzing attenuation characteristics of

vibration, and G-value analysis for examining a blasting condition.

**[0088]** The auto-correlation function used for blast vibration characteristics may be mainly utilized when the  
5 periodicity of specific vibration is intended to be checked. Through the auto-correlation function, it is possible to check the precision of the detonation delay time in accordance with the embodiment of the present invention.

**[0089]** Table 2 shows mean values obtained through the  
10 blasting results of the general blast method and the new blast method in which electronic detonators are arranged in the cut region and the contour region and non-electric detonators are arranged in the other regions. FIGS. 17 and 18 are waveform diagrams illustrating the results.

15

**[0090]** [Table 2] Data sampling for auto-correlation analysis

| Sample No | Instrument | Measurement results (peak particle velocity) |       |       |            |                    |
|-----------|------------|----------------------------------------------|-------|-------|------------|--------------------|
|           |            | Vibration (cm/sec)                           |       |       |            |                    |
|           |            | Tran.                                        | Vert. | Long. | Peak value |                    |
| N-1       | BA14350    | 0.906                                        | 0.705 | 0.643 | 0.906      | General method 1st |
| N-2       | BA18813    | 0.241                                        | 0.321 | 0.346 | 0.346      | General method 1st |
| N-3       | BA14350    | 0.522                                        | 0.781 | 0.638 | 0.781      | General method 2nd |
| N-4       | BA18813    | 0.179                                        | 0.278 | 0.186 | 0.278      | General method 2nd |
| E-1       | BA14350    | 0.679                                        | 0.605 | 0.638 | 0.679      | New method 1st     |
| E-2       | BA18813    | 0.186                                        | 0.344 | 0.259 | 0.344      | New method 1st     |
| E-3       | BA14350    | 0.525                                        | 0.71  | 0.594 | 0.71       | New method 2nd     |
| E-4       | BA18813    | 0.152                                        | 0.329 | 0.217 | 0.329      | New method 2nd     |

**[0091]** In FIGS. 17 and 18, the vertical axis indicates an auto-correlation coefficient. When each peak value approaches 1, it means that the independent waveform is reliably maintained. Furthermore, the horizontal axis indicates the periodicity of the delayed times, through which it can be checked that detonation is performed at an accurate delayed time.

**[0092]** Referring to FIGS. 17 and 18, it can be seen that the interval between delayed times is closely related to the periodicity of the auto-correction. When the electronic

detonators are utilized in the new blast method, the respective waveforms are independently operated so as not to overlap each other. Thus, the new blast method has the advantage over the general blast method, in terms of vibration control.

**[0093]** In the general blast method as illustrated in FIG. 17, clear periodicity is not detected, and the auto-correlation coefficients in the vertical-axis direction have low values. That is, the general blast method shows irregular waveforms.

When the waveforms are irregular, it means that vibration overlapping frequently occurs and scattering severely occurs in actual vibration prediction. As a result, the waveforms of the samples E-2 and E-4 of FIG. 18 have the advantage in terms of vibration control. That is, it can be seen that the new blast method, in which electronic detonators are applied to the cut region, has the advantage over the general blast method, in terms of vibration control.

**[0094]** The regression analysis is utilized to examine a series of vibration propagation characteristics from a blasting position to a specific position. In particular, the vibration propagation characteristics obtained by the regression analysis are mainly examined through a function of charge weight depending on distance, and the regression analysis is used to predict vibration through a statistical

process and calculate an allowable charge weight per delay.

**[0095]** In the construction site illustrated in FIG. 12, the coordinate values of a blasting position and a measurement position were measured to accurately measure the distance  
5 between the blasting position and the measurement position. At this time, vibration measurement results at the blasting position and the measurement position were utilized as basic information of the regression analysis and the G-value analysis.

10 **[0096]** FIG. 19 is a graph illustrating results of the vibration regression analysis using a square-root scaled distance. Referring to FIG. 19, when the scaled distance is set in the range of  $38\text{m/kg}^{1/2}$  to  $158\text{m/kg}^{1/2}$ , the new blast method has a vibration reduction effect of about 30% in  
15 comparison with the general blast method. Such a vibration reduction effect may be obtained through electronic detonators having a precise delayed time. Furthermore, when electronic detonators are additionally arranged in a part of the stopping region as illustrated in FIG. 11, it  
20 is expected that the vibration reduction effect will increase.

**[0097]** The G-value analysis is an analysis method for examining elements which may have an influence on amplification of vibration, in addition to the distance and  
25 the charge weight. The elements may include the type of

blasting such as bench blasting or tunnel blasting, a blasting condition on whether a burden and a space are large or small, a specific charge such as over-charge or under-charge, delayed time precision, and vibration waveform overlapping.

**[0098]** FIGS. 20 and 21 are graphs comparatively illustrating distributions of G-values. Referring to FIGS. 20 and 21, the mean value of the G-values in the general blast method is 424.2, and the mean value of the G-values in the new blast method is 275.4. At this time, the standard deviation (STDEV) of the general blast method is 166.5, and the standard deviation of the new blast method is 115.3. In the new blast method, a lot of vibration occurs where the G-value is low, compared to the general blast method.

This means that each blasting operation of the new blast method was more stably performed than in the general blast method, due to the precision of delayed time. In tunnel blasting, the blast sequence is an important element. When each blast hole is accurately detonated according to the blast sequence, it means that the blasting is performed in a state where the blast condition is set to a favorable condition at the blast time of each blast hole. Thus, vibration may be controlled to a target vibration value or less. In the opposite case, however, since blasting is performed in a state where the blast condition is poor,

vibration may be amplified to cause scattering. Thus, it is difficult to control the vibration to a target vibration value or less.

**[0099]** [Table 3] Regression analysis result for vibration

5 comparison

|                      | Regression analysis comparison<br>(95% reliability comparison) |                    | G-value comparison<br>( $V=GW^{1.0}D^{1.8}$ ) |                     |
|----------------------|----------------------------------------------------------------|--------------------|-----------------------------------------------|---------------------|
|                      | Regression analysis result                                     | Increase /decrease | Mean value                                    | Increase / decrease |
| New blast method     | K = 1296.12<br>n = -2.016                                      | ▼ 30%              | G = 275.4                                     | ▲ 35%               |
| General blast method | K = 1819.90<br>n = -2.010                                      |                    | G = 424.2                                     |                     |

**[00100]** Through the regression analysis result shown in Table 3, it is expected that the new blast method will reduce vibration by about 30% in comparison to the general blast method. Furthermore, through the G-value analysis result, it is expected that the new blast method will reduce vibration by about 35% in comparison to the general blast method. When the distribution of G-values converges to a low value and the scattering decreases, vibration may be reliably predicted. Thus, a more effective blast plan may be established in the future.

**[00101]** Next, the advance rate, the fragmentation rate,

the over-break, and the rock damage area in terms of the constructability and economical feasibility in the blast system in accordance with the embodiment of the present invention will be analyzed as follows.

5   **[00102]**       The evaluation for constructability and economical feasibility was performed in a tunnel between SEOK-DONG and SO-SA in Korea. Each of the new blast method and the general blast method was performed five times so as to examine the change of over-break and advance rate.

10   **[00103]**       First, the effect of precise detonation of electronic detonators disposed in the contour region 30 in accordance with the embodiment of the present invention will be examined.

15   **[00104]**       FIGS. 22 and 23 are diagrams illustrating a test blast pattern for evaluating over-break in the new blast method. FIGS. 24 and 25 are diagrams illustrating a test blast pattern in the general blast method.

20   **[00105]**       In the new blast method in accordance with the embodiment of the present invention, a V-cut method was applied to evaluate over-break, an advance rate, and a fragmentation rate, and seismic exploration and core boring were performed to evaluate the damage of rock.

25   **[00106]**       In general, the occurrence of over-break is influenced by an over-charge, a delayed time, and a drilling error. Furthermore, the advance rate has close

relation to a cut blast pattern and a blast mechanism, and the precision of delayed time has a great effect on the advance rate. Thus, in order to reduce the occurrence of over-break and increase the advance rate, an accurate  
5 delayed time is required. In the present embodiment, as electronic detonators are arranged in the cut region and the contour region, the occurrence of over-break may be minimized, and the advance rate may be increased.

**[00107]** As the over-break evaluation method in  
10 accordance with the embodiment of the present invention, a 3D scanning method was adopted. The results of the 3D scanning method may be obtained by analyzing the entire tunnel in three dimensions. Thus, in order to calculate actual over-break, the influence of the front face and the  
15 floor face of the tunnel was removed to standardize the entire surface into an effective analysis section for analyzing the over-break.

[00108]

[Table 4] Over-break analysis result

| note                       |                               |      | ▼<br>39.3% |        |        |        |       |      |      |      |       |     |            |
|----------------------------|-------------------------------|------|------------|--------|--------|--------|-------|------|------|------|-------|-----|------------|
| Average over-break         | Over-break rate (%)           | 4.2  | 3.449      | 4.2    |        |        |       |      |      |      |       |     |            |
|                            | Volume per unit length (m³/m) |      |            |        |        |        |       |      |      |      |       |     |            |
| Over-break                 | Over-break rate (%)           | 4.40 |            |        |        |        |       |      |      |      |       |     |            |
|                            | Volume per unit length (m³/m) | 3.90 |            |        |        |        |       |      |      |      |       |     |            |
|                            | Over-break volume (m³)        | 4.50 |            |        |        |        |       |      |      |      |       |     |            |
| Under-break (m³)           |                               | 4.30 |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               | 4.20 |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
| Integrated volume (m³)     |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
| Scan volume (m³)           |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
| Design volume (m³)         |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
| Analysis section (m²)      |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
| Analysis section width (m) |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
| Order                      |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
|                            |                               |      |            |        |        |        |       |      |      |      |       |     |            |
| New blast method           | 1                             | 3.2  | 80.9       | 259.1  | 270.2  | 270.5  | 0.213 | 11.4 | 3.56 | 4.40 | 3.449 | 4.2 | ▼<br>39.3% |
|                            | 2                             | 2.8  | 80.9       | 226.7  | 235.2  | 235.5  | 0.315 | 8.8  | 3.15 | 3.90 |       |     |            |
|                            | 3                             | 3.1  | 80.9       | 251.0  | 262.0  | 262.3  | 0.256 | 11.2 | 3.64 | 4.50 |       |     |            |
|                            | 4                             | 3    | 80.9       | 242.9  | 253.1  | 253.3  | 0.218 | 10.4 | 3.48 | 4.30 |       |     |            |
|                            | 5                             | 3    | 80.9       | 242.9  | 252.9  | 253.1  | 0.178 | 10.2 | 3.40 | 4.20 |       |     |            |
|                            | Total                         | 15.1 |            | 1222.6 | 1273.6 | 1274.8 | 1.181 | 52.1 |      |      |       |     |            |
| General blast method       | 1                             | 2.9  | 80.9       | 234.8  | 249.4  | 250.7  | 1.354 | 15.9 | 5.50 | 6.8  | 5.684 | 7.0 |            |
|                            | 2                             | 3.3  | 80.9       | 267.2  | 286.6  | 287.5  | 0.824 | 20.3 | 6.15 | 7.6  |       |     |            |
|                            | 3                             | 3    | 80.9       | 242.9  | 259.2  | 260.6  | 1.425 | 17.7 | 5.91 | 7.3  |       |     |            |
|                            | 4                             | 3    | 80.9       | 242.9  | 258.5  | 259.9  | 1.315 | 17.0 | 5.66 | 7.0  |       |     |            |
|                            | 5                             | 2.5  | 80.9       | 202.4  | 213.5  | 215.3  | 1.832 | 12.9 | 5.18 | 6.4  |       |     |            |
|                            | Total                         | 14.7 |            | 1190.2 | 1267.4 | 1274.5 | 6.75  | 83.9 |      |      |       |     |            |

5 [00109] Referring to Table 4, the entire over-break rate for the test section in the new blast method is 4.2%, and

the entire over-break rate for the test section in the general blast method is 7.0%. That is, the average over-break per meter of the new blast method was reduced by about 39.3%, compared to that of the general blast method.

5 The design volume is calculated on the basis of the effective analysis section width and the analysis section, and the scan volume is also obtained on the basis of the effective analysis section width and the analysis section through the 3D scanning values and indicates a volume  
10 including only an over-break volume except for an under-break volume. The integrated volume corresponds to the scan volume when under-break doesn't exist. However, when under-break exists, the integrated volume is obtained by adding the under-break volume to the scan volume, and the  
15 over-break corresponds to a value obtained by subtracting the design volume from the integrated volume. The average over-break is calculated by considering all test sections.

**[00110]** Even when the advance rate is analyzed, the influence of the tunnel face may be removed with reference  
20 to a drilling pattern of a computer jumbo drill, because the tunnel face before and after blast is not smooth. Then, a drilling depth and an advance may be calculated on the basis of the result obtained by 3D scanning, in order to evaluate the advance rate.

25

**[00111]** [Table 5] Advance rate analysis result

|                            | Order   | Drilling<br>Depth (m) | Advance<br>(m) | Advance<br>rate (%) |         |
|----------------------------|---------|-----------------------|----------------|---------------------|---------|
| New blast<br>method        | 1       | 3.5                   | 3.4            | 97.2                | ▲ 10.4% |
|                            | 2       | 3.1                   | 3.0            | 98.0                |         |
|                            | 3       | 3.5                   | 3.4            | 96.6                |         |
|                            | 4       | 3.4                   | 3.3            | 98.2                |         |
|                            | 5       | 3.5                   | 3.4            | 97.4                |         |
|                            | Average |                       |                | 97.48               |         |
| General<br>blast<br>method | 1       | 3.6                   | 3.2            | 88.3                |         |
|                            | 2       | 3.9                   | 3.4            | 87.5                |         |
|                            | 3       | 4.0                   | 3.4            | 86.1                |         |
|                            | 4       | 3.6                   | 3.2            | 89.2                |         |
|                            | 5       | 2.8                   | 2.5            | 90.5                |         |
|                            | Average |                       |                | 88.32               |         |

5 **[00112]** As shown in Table 5, the average advance rate of  
the test sections in the new blast method corresponds to  
97.48%, and the average advance rate of the test sections  
in the general blast method corresponds to 88.32%, which  
means that the advance rate of the new blast method was  
10 improved by 10.4% in comparison to the general blast method.

**[00113]** Referring to the analysis results for the over-  
break and the advance rate in Tables 4 and 5, it can be  
seen that the new blast method, utilizing the blast  
mechanism in which electronic detonators are arranged in  
15 the cut region and the contour region, is superior to the  
general blast method.

**[00114]** Next, the evaluation for the fragmentation rate will be described.

**[00115]** In order to analyze the fragmentation rate, an analysis method using a video image is mainly utilized.

5 Elements having an influence on the fragmentation rate may include a specific charge, a burden, and a spacing. In the tunnel blast, the fragmentation rate is significantly affected by the stopping region blast mechanism.

**[00116]** Table 6 shows final analysis results based on  
10 test blasting in accordance with the embodiment of the present invention.

**[00117]** [Table 6] Fragmentation rate analysis result

|                            |          | First  | Second | Third  | Fourth | Fifth  | Average |        |
|----------------------------|----------|--------|--------|--------|--------|--------|---------|--------|
| New<br>blast<br>method     | P50 (mm) | 105.85 | 110.32 | 120.90 | 76.84  | 140.49 | 110.88  |        |
|                            | P80 (mm) | 169.65 | 164.46 | 206.49 | 131.28 | 212.91 | 176.96  | ▼40.9% |
|                            | TOP (mm) | 263.17 | 244.79 | 416.19 | 265.76 | 314.05 | 300.79  |        |
|                            | S30 (%)  | 100    | 100    | 93.03  | 100    | 98.66  | 98.34   |        |
| General<br>blast<br>method | P50 (mm) | 241.95 | 142.07 | 93.21  | 142.57 | 174.96 | 158.95  |        |
|                            | P80 (mm) | 351.44 | 261.54 | 250.01 | 207.91 | 425.09 | 299.20  |        |
|                            | TOP (mm) | 470.99 | 414.94 | 372.91 | 310.69 | 630.67 | 440.04  |        |
|                            | S30 (%)  | 66.14  | 88.05  | 88.76  | 98.89  | 67.78  | 81.92   |        |

\* S30: distribution of fragments having a specific size of  
15 30cm or less

**[00118]** Referring to Table 6, the analysis results of the general blast method show that the average size of fragments is 15.9cm, the maximum size of fragments is 44cm, and the distribution S30 of fragments having a specific

size is 81.92%. Furthermore, the analysis results of the new blast method show that the average size of fragments is 11.1cm, the maximum size of fragments is 30cm, and the distribution S30 of fragments having a specific size is 98.34%. Based on the size P80 (mm), the fragmentation rate of the new blast method was reduced by 40.9% in comparison to the general blast method.

**[00119]** The blast operation for the cut region shows a relatively favorable fragmentation rate because the specific charge (charge weight per unit volume) is high. However, since the blast operation for the stopping region is affected by the blast situation of the cut region, whether the blast operation for the cut region was reliably performed or not becomes a main issue. This is related to a factor which increases the advance rate. In the new blast method, the utilization of electronic detonators in the cut region is determined as a factor to improve the fragmentation rate. The angle-cut pattern based on the V-cut pattern, which is performed under a one-free-surface condition, may induce effective fragmentation for the cut region through precise simultaneous detonation, and the effective fragmentation for the cut region may induce an effective blast operation for the stopping region.

**[00120]** Finally, the rock damage area analysis will be described.

**[00121]** For the rock damage area analysis, seismic exploration and core boring were used. As a seismic exploration method for each section, a down-hole exploration method was used. The core boring was utilized  
5 as an evaluation standard for rock damage area through RQD values and laboratory seismic exploration.

**[00122]** FIG. 26 illustrates the final result of the seismic exploration for evaluation of rock damage area. As illustrated in FIG. 26, there is a slight difference or no  
10 difference in seismic velocity between the new blast method and the general blast method at a depth of 0 to 5m, based on a direction perpendicular to the fracture surface of the contour region. For the seismic velocity at a depth of 1.0 to 1.5m, however, the new blast method exhibits a higher  
15 velocity by about 637m/sec to 853m/sec than the general blast method. Furthermore, the seismic velocity of the new blast method starts to converge to the seismic velocity of the parent rock at a depth of about 1.0m, but the seismic velocity of the general blast method starts to converge to  
20 the seismic velocity of the parent rock at a depth of 1.5 to 2.0m. According to the results obtained by comparing the seismic velocities, the damage area of the tunnel wall from the surface in the new blast method ranges from 0.5m to 1.0, but the damage area of the tunnel wall from the  
25 surface in the general blast method ranges from 1.0m to

1.5m.

**[00123]** For a plurality of sections of the tunnel wall, in which the seismic exploration was performed for each depth, core samples were collected. Then, the collected  
5 core samples were carried to a laboratory to perform a test.

**[00124]** Total 10 core samples were collected for the new blast method using electronic and non-electric detonators, and total 8 core samples were collected for the general blast method using non-electric detonators. Then, the  
10 damage of the tunnel wall was compared through rock quality designation (RQD) evaluation, after each blast operation. Table 6 shows the relation between the state of rock and RQD.

**[00125]** [Table 7] State of rock and RQD

15

| RQD (%)  | Rock State | Note |
|----------|------------|------|
| 0 ~ 25   | very poor  |      |
| 25 ~ 50  | poor       |      |
| 50 ~ 75  | normal     |      |
| 75 ~ 90  | good       |      |
| 90 ~ 100 | very good  |      |

**[00126]** Tables 8 and 9 show RQD values of the samples collected in the test blast site, measured on the basis of the relation between rock state and RQD in Table 7.

20

**[00127]** [Table 8] Core analysis result of present invention

| Sample No. | Core length (cm) | Collected core length (cm) | RQD  | Note   |
|------------|------------------|----------------------------|------|--------|
| E1 L       | 55               | 32                         | 58.2 |        |
| E1 R       | 60               | 38                         | 76.0 |        |
| E2 L       | 63               | 41                         | 65.1 |        |
| E2 R       | 50               | 40                         | 80.0 |        |
| E3 L       | 63               | 44                         | 69.8 |        |
| E3 R       | 65               | 38                         | 58.5 |        |
| E4 L       | 62               | 46                         | 74.2 |        |
| E4 R       | 61               | 23                         | 37.7 |        |
| E5 L       | 60               | 33                         | 55.0 |        |
| E5 R       | 64               | 50                         | 78.1 |        |
| Average    |                  |                            | 65.3 | Normal |

5

**[00128]** [Table 9] Core analysis result of general blast method

| Sample No. | Core length (cm) | Collected core length (cm) | RQD   | Note |
|------------|------------------|----------------------------|-------|------|
| E1 L       | 50               | 27                         | 54.0  |      |
| E1 R       | 55               | 11                         | 20.0  |      |
| E2 L       | 60               | 0                          | 0.0   |      |
| E2 R       | 60               | 38                         | 63.3  |      |
| E3 L       | 65               | 35                         | 53.8  |      |
| E3 R       | 62               | 22                         | 35.5  |      |
| E4 R       | 60               | 26                         | 43.3  |      |
| E5 R       | 53               | 38                         | 71.7  |      |
| Average    |                  |                            | 42.70 | Poor |

10 **[00129]** Tables 8 and 9 show results obtained by

analyzing cores collected through core boring. In the new blast method, the average of RQD values is 65.3 corresponding to the moderate rock, but in the general blast method, the average of RQD values is 42.7  
5 corresponding to the poor level or weathered rock.

**[00130]** The results of the seismic exploration for each section, the RQD analysis of core collecting, the laboratory seismic exploration, which were performed to evaluate the rock damage area, indicate that the new blast  
10 method may reduce rock damage in comparison to the general blast method. That is, the new blast method has the advantage in damage control over the general blast method. The rock damage area is partially related to the occurrence of over-break. When the rock damage area is small, it  
15 means that the method has an advantage in terms of over-break control. This effect is decided from stress concentration by accurate simultaneous detonation of the electronic detonators used in the contour region. Thus, as the electronic detonators are used in the cut region and  
20 the contour region in which a precise delayed time is required due to the characteristics of the tunnel blast, the new blast method may obtain a more excellent blast effect than the general blast method.

**[00131]** Next, the economic feasibility will be analyzed  
25 through the comparison between the new blast method and the

general blast method.

**[00132]** In terms of vibration control, the new blast method and the general blast method may be compared to each other, based on a standard blast pattern.

5 **[00133]** In the general blast method, it is possible that drilling a large-diameter hole in cut region is performed 50m at once, and a drilling period is one day. During this period, a blast operation cannot be performed. At this time, suppose that a loss cost for this period is  
10 20,000,000 won/day. As a result, the new blast method may reduce the drilling cost by about 14.9% in comparison to the general blast method, based on an extension of 50m.

**[00134]** Analyze the economical feasibility in terms of over-break control, the blast method in accordance with the  
15 embodiment of the present invention may reduce over-break by about 39.3% in comparison to the general blast method. The economical feasibility analysis was performed by examining a difference in over-break between the general blast method and the new method and then converting the  
20 difference into shotcrete. That is, when the cost required for the electronic detonators used in the contour region so as to control over-break according to the new blast method and increase of over-break occurring in the general blast method is converted into shotcrete. The result of  
25 comparison in terms of the economical feasibility, the new

blast method is larger by 15.4% than that of the general blast method.

**[00135]** In accordance with the embodiments of the present invention, it is possible to obtain the following effects.

**[00136]** First, as electronic detonators are arranged in a cut region and a contour region of a single blast excavation section and non-electric detonators are arranged in the other regions, vibration, over-break, and under-break may be efficiently controlled, and an advance rate may be improved.

**[00137]** Second, as the detonators are blasted with a proper delay time in consideration of a detonator delay time of each region in the single blast excavation section and an error range of the non-electric detonator, the detonation operations for the respective regions may be sequentially performed, and the occurrence of cut-off or misfire may be suppressed. Thus, it is possible to improve detonation stability, construction stability, and economical feasibility.

**[00138]** Third, as the blast method in which electronic detonators are arranged in the cut region and a part of the stopping region uses a precise delayed time, a vibration peak value may be reduced in comparison to the general blast method. Since the respective waveforms are

independently operated so as not to overlap each other,  
blasting vibration may be reliably reduced.

**[00139]** While the present invention has been described  
with respect to the specific embodiments, it will be  
5 apparent to those skilled in the art that various changes  
and modifications may be made without departing from the  
spirit and scope of the invention as defined in the  
following claims.

**CLAIMS:**

1. A blast system using a combined pattern of electronic and non-electric detonators, comprising:

5 a blast excavation area divided into a cut region formed in the center of the excavation area, a stopping region formed around the cut region, a contour region formed at the outermost part of the stopping region, and a floor region formed at the bottom of the cut region;

10 electronic detonators arranged in the cut region and the contour region of the blast excavation area and connected through a leading wire;

non-electric detonators arranged in the stopping region and the floor region of the blast excavation area  
15 and connected through a leading wire; and

an electronic-detonator blasting machine for blasting the electronic detonators and the non-electric detonators with a delay time,

wherein the cut region comprises a horizontal cut  
20 pattern in which one or more large-diameter uncharged holes are arranged.

2. A blast system using a combined pattern of electronic and non-electric detonators, comprising:

a blast excavation area divided into a cut region formed in the center of an excavation section, a stopping region formed around the cut region, a contour region formed at the outermost part of the stopping region, and a  
5 floor region forming the cut region;

electronic detonators arranged in the cut region and the contour region of the blast excavation area and connected through a leading wire;

non-electric detonators arranged in the stopping  
10 region and the floor region of the blast excavation area and connected through a leading wire; and

an electronic-detonator blasting machine for blasting the electronic detonators and the non-electric detonators with a delay time,

15 wherein an angle-cut pattern based on a V-cut pattern is formed in the cut region.

3. The blast system of claim 1 or 2, wherein a delay time of 10 to 50ms is set to each hole of the cut  
20 region.

4. The blast system of claim 1 or 2, wherein a delay time of each detonator in the cut region and the contour region, in which the electronic detonators are

arranged, is set in the range of 10 to 20ms for hard rock (high strength), in the range of 15 to 25ms for moderate rock (medium strength), or in the range of 25 to 35ms for soft rock (low strength).

5

5. The blast system of claim 1 or 2, wherein electronic detonators are additionally arranged in a part of the stopping region, in order to expand the cut region.

10

6. A blast method using a combined pattern of electronic detonators and non-electric detonators, comprising:

15

a first step of dividing a blast excavation area into a cut region, a stopping region, a contour region, and a floor region according to a rock mass condition of ground to be excavated;

20

a second step of arranging electronic detonators in the cut region and the contour region, arranging non-electric detonators in the stopping region and the floor region, and connecting the electronic detonators and the non-electric detonators through leading wires;

a third step of setting a delay time in consideration of a detonator delay time for each hole in the divided regions of the blast excavation area and an error range of

the detonators; and

a fourth step of performing detonation according to the following sequence: the cut region, the stopping region, the floor region, and the contour region, with the delay  
5 time of the third step.

7. The blast method of claim 6, wherein the first step comprises forming a horizontal cut pattern in the cut region, the horizontal cut pattern having one or more  
10 large-diameter uncharged holes arranged therein.

8. The blast method of claim 6, wherein the first step comprises drilling the cut region according to an angle-cut pattern based on a V-cut pattern.  
15

9. The blast method of claim 6, wherein the second step comprises arranging second electronic detonators in a part of the stopping region.

20 10. The blast method of claim 6, wherein in the third step, a delay time of each detonator in the cut region and the contour region, in which the electronic detonators are arranged, is set in the range of 10 to 20ms for hard rock (high strength), in the range of 15 to 25ms

for moderate rock (medium strength), or in the range of 25 to 35ms for soft rock (low strength)

11. The blast method of claim 10, wherein a delay  
5 time of  $\pm 5$  to 10ms is added to the delay time of each  
detonator, in consideration of mucking speed of rock based  
on an advance.

12. The blast method of claim 6, wherein the third  
10 step comprises determining a delay time through analysis of  
waveforms obtained by performing a small-scale test blast  
for a section which is extremely sensitive to occurrence of  
vibration.

13. The blast method of claim 6, wherein in the  
15 blast sequence of the fourth step, the roof and the left  
and right wall of the contour region are divided into two  
or three regions in such a range that does not exceed an  
allowable charge weight per delay, in order to control  
20 charge weight per delay, and simultaneous delay blast is  
then performed for each region.

14. The blast method of claim 6, wherein in the  
blast sequence of the fourth step, an initial delay time of

the stopping region in which the non-electric detonators are arranged is reflected by adding a delay time of 200 to 500ms to a final delay time of the cut region.

5           15. The blast method of claim 6, wherein in the blast sequence of the fourth step, a constant delay time of about 10ms is sequentially applied to contour hole lines of the contour region in consideration of an allowable vibration level, and delay blast is alternately performed  
10 in the left and right sides by turns.

          16. The blast method of claim 6, wherein in the blast sequence of the fourth step, when the contour region having electronic detonators arranged therein is started, a  
15 delay time of 300 to 1,000ms is set in consideration of a delay time of a non-electric detonator which is finally detonated in the floor region and an allowable error of the non-electric detonator.

20           17. A blast method using a combined pattern of electronic detonators and non-electric detonators, comprising:

          a first step of dividing an excavation area of open pit adjacent to an urban area or obstacle into a primary

stopping region, a secondary stopping region, and an excavation line region;

a second step of arranging electronic detonators in the primary stopping region and the excavation line region,  
5 arranging non-electric detonators in the secondary stopping region, and connecting the electronic detonators and the non-electric detonators through leading wires;

a third step of setting a delay time of 10 to 50ms for each detonator in the divided regions of the excavation  
10 area of open pit and setting a surface delay time of 100 to 500ms, in order to induce each definite independent waveform through delay blast of each hole formed in the excavation area of open pit; and

a fourth step of performing detonation according to  
15 the following sequence: the primary stopping region, the secondary stopping region, and the excavation line region, with the delay time of the third step.