Article

Fly-rock incidents by blasting at three quarries

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Abstract

There were six quarry sites owned in separate companies, which were lined together on a shore side in the north of Kyusyu in Japan. During 1998 to 2000, fly-rock incidents by blasting occurred at three quarries in there. Even worse, those occurred at a time continuously every year, and worse still, two of those were located next to each other. There were some site facilities within each quarry site concerned and some offices with the parking space, a factory or a shop, etc. around them. Fly-rocks by blasting injured and damaged to a blaster in charge on evacuation on the site and a pickup truck stopping at his side, a factory employee driving a car and its body, the roof of a factory building, a truck parking at a the shop and etc.

An author got an opportunity to inspect then blasting situation and the later on-site condition in response to the request from prefectural administration authorities as well as each quarry manager. The inspection for each case found that whole the round was not completely of over-charge but a certain hole or the part on the blast site became a source origin of the fly-rock, that seems to have involved a sharp change in condition on the site deeply, that is, local existence of some poor rock-quality with dense joints or widely open fractures, some hole filled with water, some hole-deviation due to uneven crest face, an irregularity of blast face and etc.

In order to minimize the danger of fly-rock, needless to say, it is important that any change in such the condition is caught sharply on the blast site and suitable means (with some precaution) are taken certainly depending on the local change. However, for that, blasting should be done with room sufficiently, and it will be necessary that a mutual understanding and a close cooperation relation between a person in charge of blasting work and one in charge of subsequent loading and hauling work etc. will be required. And above all, the quarry manager's recognition about that seems indispensable.

1. Introduction

There were six quarry sites owned in separate companies, which were lined together on a shore side in the north of Kyusyu in Japan. During 1998 to 2000, fly-rock incidents on blasting occurred at three quarries in there. Even worse, the incident occurred at a time continuously every year, and worse still two of them were located next to each other.

Riprap (for use of reclamation) had usually been mainly extracted in this area, and therefore, blasting had been carried out not only using a blasting pattern suited to produce larger size blocks for such use but also taking account of environmental conditions (blast vibrations etc.) around each quarry-site.

Face blasting with down holes (so called bench blasting) had been applied at two of them. The drilling pattern was the one in which burden is much longer than hole spacing unlike common practice. And face blasting with two rows of holes cross front face (like so called collapse blasting) had been applied at another quarry. The quarry was faced with severe problems on blast vibrations to a hospital locating immediately behind the blast site (interval distance: approximately 30~40m), so the in-hole charge was extremely limited and each hole was fired taking quite long delay interval with some discrete numbers of DS detonator.

An author inspected then blasting situation and on-site condition after the blasting in response to the request from prefectural administration authorities as well as each quarry manager.

Some findings about each the case will be described and some probable causes of the fly-rock and technically possible means for minimizing its danger will be considered in this paper.

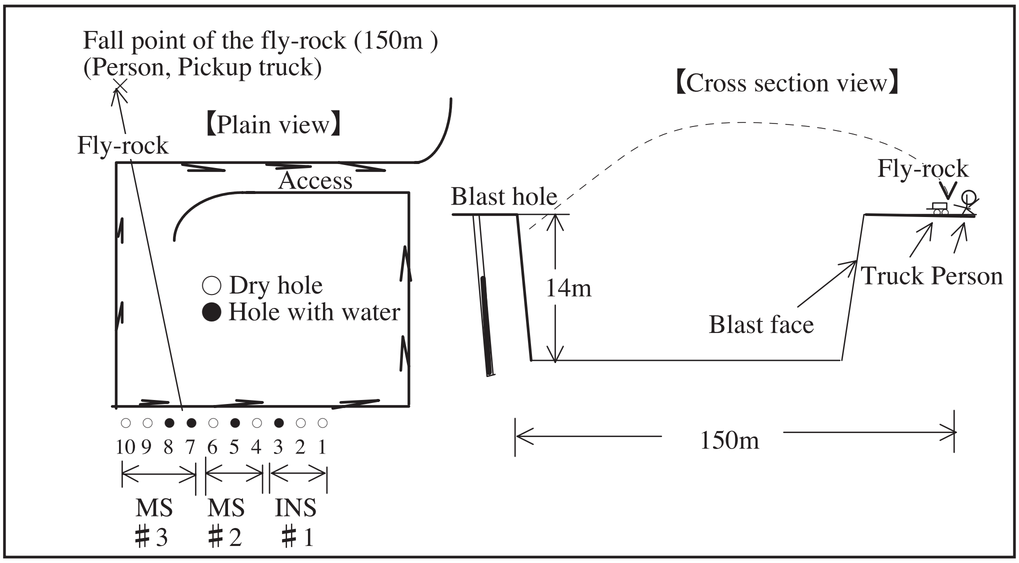

Fig. 1 Fall point of the fly-rock and blast site (A quarry).

2. The fly-rock incidents at A quarry (case 1)

On August23, 1997, when blasting (type of blasting: face blasting with down hole, total charge; 310kg, hole numbers; 10 holes, millisecond delay detonator; delay number 1, 3, 5) was done, some fly-rocks struck a person (involving in blasting work) on the thigh and a pickup truck (load capacity: 500Kg) thereby. The person was standing ahead on the slant from the blast face then. His left thigh was seriously fractured by some fist-sized lump rock. Some lump rocks flew also into the pickup truck and damaged seriously to the truck body and its inside. Both the person and the nearby pickup truck were located about 150m away from the blast site. (Fig. 1)

Blast holes were drilled down below the ground level and some of them were filled with a lot of water, whereby, a combination of polyethylene cartridge ANFO and #3 Kiri dynamite was used for those holes and no dewatering before loading was done. On the other hand, in the case of dry holes, bulk ANFO only was used.

2.1 Blasting pattern at A quarry (Fig. 1 and Fig. 2)

Blast type: face blasting with down holes (so called bench blasting) Face height (or bench height): 14m
Rock type: hard sandstone Borehole diameter: 70mm
Borehole angle: 80° Borehole length: 15m
Number of holes: 10 Burden: 4m Hole spacing: 2.5m
Explosive consumption: Dynamite 90kg,
PE packaged ANFO: 45kg,
Bulk ANFO 175kg, Total 310kg
Detonator consumption: Instantaneous detonator (#1) 3 pieces, Millisecond delay detonator (#2) 3 pieces, Millisecond delay detonator (#3) 4 pieces,
Total detonators 10 pieces

2.2 Condition of fragments scattering after the blasting

Most fragments were piling up within the range of approximately 20-30m ahead of the bench face, while small size fragments (nearly 10-20cm) were scattering far (to a distance of approximately 60-70m) over an area where the fragments were piling up especially ahead of No.7-No.8 hole. (Fig. 1) On the left-hand face, many joints developing in every direction were exposed.

2.3 View about the blasting pattern applied at A quarry

2.3.1 Drilling pattern and In-hole charge

At the quarry, blasting was done by the drilling pattern in which the burden length was much larger than the hole-spacing in order to extract the riprap for reclamation. Hole spacing / burden =0.625. This pattern is what is based on the concept contrary to so-called wide space blasting that is applied in order to make the fragment smaller, and it tends to make the fragments move to a long distance. Meanwhile, such the type of blasting as applied there tends to make the fragments larger and make the rock movement ahead of the face shorter. Therefore, in nature, the pattern should have little danger of fly-rock ahead of the face. However, really, several pieces of rock jumped over the front rock wall across the ground floor in front of the blast face and got far.

Then, we tried to check up whether the blasting pattern was the one with over-charge or not, by applying the following equation[1] that has used generally in bench blasting.

$$L = C \cdot D \cdot W \cdot H \qquad (1)$$

Where, L : in-hole charge (kg), D: Hole spacing (m), W: Burden (m), H: Bench height (m), C : Blasting coefficient (= specific charge Kg/m^3)

In case of the dry hole;

Substituting L = 37.75kg, D = 2.5m,W = 4m, H = 14m to the above equation, .

$$C = 37.75/(2.5 \cdot 4 \cdot 14) = 0.255 \text{ (ANFO)}$$

In case of the hole with water;

Substituting L = 37.75kg, D = 2.5m, W = 4m and H = 14m to the above equation.

$$C = 26.25/(2.5 \cdot 4 \cdot 14) = 0.188 \text{ (dynamite and ANFO)}$$

Table 1 Blasting coefficient in case of bench blasting [1].

Type of rock	Dynamite	ANFO
Soft rock	0.1 ~ 0.2	0.2 ~ 0.3
Medium hard rock	0.2 ~ 0.3	0.3 ~ 0.4
Hard rock	0.3 ~ 0.4	Over 0.4

These above values correspond to that in case of soft rock in Table 1.[1] Judging from rock quality exposed on the blast site, those charges do not necessarily seem so much as they become responsible for the fly-rock incident.

2.3.2 Stemming

In case of the hole filled with water (Fig. 2), calculating from the following length of a given explosive cartridge used, stemming length become nearly 3m, and in case of the dry hole (Fig. 2), calculating from the bulk density (0.85g /cc), that hole become nearly 5m.

(3Kiri dynamite (50mmΦ × 750g); 31cm/cartridge, PE packaged ANFO (50mmΦ × 750g); 42cm/cartrige)

In bench blasting, etc. with two free faces, the stemming length that is equal or more to the burden length has been adopted commonly. That is, stemming length/ burden length ratio is 1.0 to 1.65. (According to Hino, the ratio is 1.65.)[2]

In case of the latter, the ratio (1.25) on calculation seems appropriate in contrast to the common ratio. Meanwhile, in case of the earlier, that on calculation becomes 0.75times of the burden, which seems too short. (Fig. 2) However, if the hole has only a little water at bottom, the cartridge in hole will probably be shrunk as much as in case of the dry hole by load from the upper part. In case of the dynamite cartridge used there, the charge can be expected to shorten substantially by load from the upper part although its degree varies by the number of cartridges commensurate with the length of hole. (But the upper portion of ANFO cartridge seems hardly shortened.)(*) Assuming that the charge portion with dynamite only is shortened fifteen percents, the in-hole charge length will be decreased from nealy 12m to nearly 11m on calculation, thus, the stemming length will be increased from nearly 3m to nearly 4m on calculation. The ratio (stemming length/burden length) in this case becomes 1.0 that seems reasonable on blasting.

In contrast, in case of the hole with so much water to overflow out of the hole and or with water at least to a extent that all cartridges hide in water after charging with, the charge length will become as calculated based to each cartridge length that is approximately equal to the sum of length in respective portions of dynamite cartridges and ANFO cartridges and nearly 12m since both the portions are expected to hardly shorten by action of the buoyancy in water.

However, in actuality the amount of water contained within hole will differ from one hole to another, so the degree of shortening also will be changed with that. Therefore, it will be impossible to predict an exact charge length only by the number of cartridges in each hole and thus there will be no certainty to be able to hold an in-hole space required for a sufficient stemming anywhere. Furthermore, in such the hole with water, some cartridge will be likely caught on a rugged hole-wall and some small rock-piece loosing around a hole will drop down once in a while on in-hole bottom or cartridge pre-loaded under loading. Also such cases will result in going up of charge head and then falling short of required stemming length.

Therefore, all holes should be loaded with explosive cartridges, checking carefully in-hole space for sufficient stemming by loading stick with scale, etc. under loading. If it is judged by checking under loading that subsequent loading will make impossible to hold a certain stemming length required due to the reason as above, then further loading should be stopped. That should be performed to avoid scattering from the bench crest even if the specific charge becomes a little smaller due to that.

(*) The degree of shortening by load will differ from one explosive to another, that will be as great as what is rich in plasticity like dynamite (paper cartridge type), in contrast, polyethylene film cartridge type explosive like cartridge ANFO will hardly shortened unless the film is broken during charging.

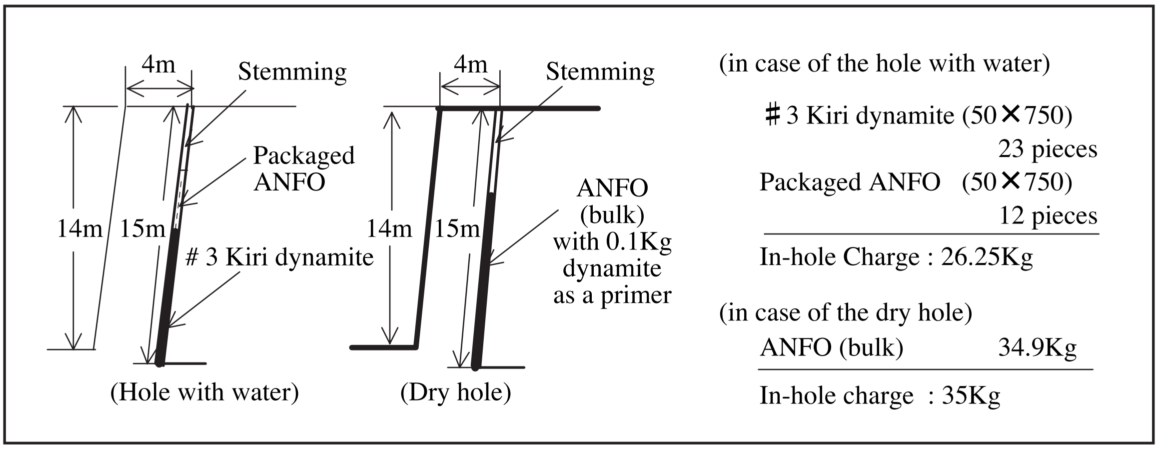

Fig. 2 Schematic representation of charging in the holes with water and dry hole (A quarry).

2.3.3 Variation in minimum burden length due to drilling deviation

An examination of the drill performance under operating on the site found that actual drilling angle tends to be out of a given angle (80°) by about 2° to 3° owing to a drill rod taken by the asperity of ground. Supposing a given angle (80°) is out to 77°, the burden at hole bottom will vary from a given burden length (4m) to approximately 2.7m by the following calculation.

$$15\text{m} \cdot \text{COS}(80°) - 15\text{m} \cdot \text{COS}(77°) = 1.3\text{m}$$

(Variance of minimum burden)

$$B = 4\text{m} - 1.3\text{m} = 2.7\text{m} \text{ (probable minimum burden)}$$

In such case, the specific charge near the hole-bottom will become greater nearly fifty percents (i.e. 4m/2.7m = 1.48 times). Furthermore, if there is some irregularity on blast face or especially there are dents on a face near the bottom, the burden length in the portion will become still shorter and thus the specific charge will increase considerably although it is not evident actually whether it existed under the blasting. For instance, supposing the depth of dents 1m, the actual burden will be decreased to 2.7 – 1 = 1.7m and thus the specific charge will increase to 4m/1.7m = 2.4 times. If such worst condition (with deviation in hole-angle + dents on face) is assumed, fly-rock may have arose due to over-charge in the portion.

2.4 Some possible causes of the fly-rock incidence

As indicated above, the specific charge on calculation for the basic blasting design that had been adopted on this site is considered not so large from the rock quality there. Therefore, at the time, the round does not seem to have been of overcharge all over. However, as long as seen from the appearance on the site that many small pieces of rock was scattered quite to a long distance ahead of the right side of blast site, some shot-hole within the area will probably have become of over-charge.

The following will be stated as the reason for having such the local overcharge.

- Burden diminishing in part due to drilling deviation.
- Burden diminishing in part due to irregularity of blast face.
- Elevation of a charge head in the hole with water that led to lacking of the length in stemming owing to failure of settling down of explosive cartridges and etc..
- Existence of extremely soft materials or high frequent joints developing locally on the blast site.
- Existence of some disturbed or extremely soft material which is not exposed on the surface

Furthermore, technically possible means to such the causes will be stated as follows.

- To make clear the geometry of the blast site by removing any loose rock completely.
- To check up carefully the on site condition such as some asperity on the blast face as well as a local variation in rock quality such as some local disturbed zone with an extremely soft material or with quite dense joints.
- To estimate any variation in the rock quality inside the ground that is not exposed on the surface, checking carefully the cuttings (e.g. color, hardness and grain size, etc.) and the drilling performance (e.g. drilling rate) .
- To ensure a given stemming length by checking carefully the space remaining within hole under loading with explosive cartridges. Especially, that will be important in case of the hole with water or with rugged wall.

However, a certain position in front of the blast face at which the victim was evacuating is regarded as be on a major direction of rock movement under blasting. The position seems never suitable for evacuating. One of the greatest causes for the fly-rock incident seems a human-induced miss on direction and distance to the evacuation position. If there is no appropriate position to look out on the site, a reasonable means such as a heavy-duty shelter, etc. will be to be brought in for protection to the fly-rock.

3. The fly-rock incident at B quarry (case 2)

On July 10,1998,when a certain blasting was done, one fly-rock incidence occurred and at the time some pieces of rock damaged to the window glass or the body of four privately-own cars parking in the parking space of a company, the slate roof of a repairing factory and two privately-own cars parking there, and the window glass and the tank of a shop warehouse and the window glass of a 2T truck parking there. Distance from the blast site to those stricken properties ranged within approximately 160m to 210m. (Fig. 3)

As above, the incidence accompanied only physical but fortunately no human damage.

3.1 Blasting pattern at the quarry (Fig. 4)

Type of blasting: face blasting with down hole
(i.e.. bench blasting)
Type of rock: hard sand stone, Bench height: 8m
Drill diameter: 70mm, Drilling length: 9m, Drilling angle: 80°, Numbers of hole: 15,
Hole spacing: 1.3m, Burden: 4.5m,
Explosives: #3 Kiri dynamite (50mm×750g) 20pieces
Instantaneous detonator 15 pieces

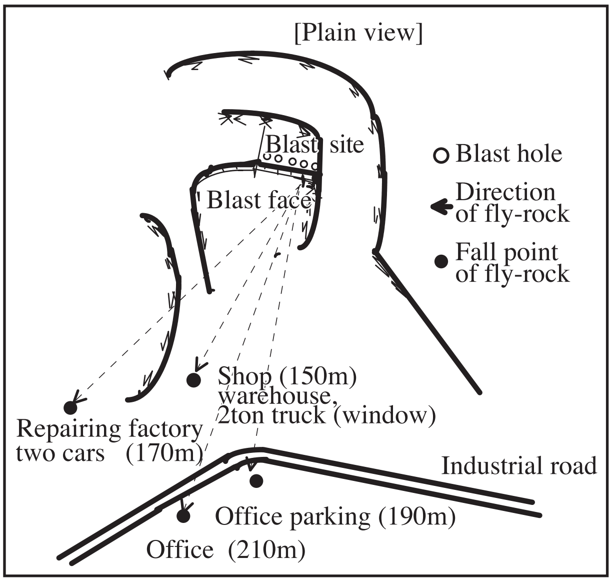

Fig. 3 Fall points of fly-rock and blast site (B quarry).

3.1.1 Drilling pattern

Blasting was done by using the drilling pattern like the one at A quarry, but the burden was still more decreased than at A quarry. It seems that this is any more a pattern like the one when a dimension stone is quarried by using black powder, etc. Such the blasting is in nature what makes such the blocks thrust forward slowly and thus keeps the rock displacement to a minimum. Therefore, that is what has less possibility of fly-rock ahead of the bench. However, in reality, fly-rocks arose in the direction.

According to Olofsson[3)], stemming/ burden ratio is 0.5-1.0, in order to give blockier fragment with an optimum blasting. The ratio at B quarry become about 0.29, that is quite small compared to the ratio. (At the quarry concerned, that is 0.625) However, there were a number of actual achievements (without fly-rock incident) that such the drilling pattern had been applied former repeatedly at the blasting site.

Therefore, such the drilling pattern itself seems to have no problem as become a cause for fly-rock at least ahead of the face although there will be a little uniqueness in the one.

3.1.2 Blasting coefficient

The blasting coefficient(C) is estimated as follows using the equation (1).

$$(C) = 15Kg/8m \times 4.5m \times 1.3m = 0.32Kg/m^3$$

This value on calculation is within the range in case of intermediate hard rock (Table 1), but is a little greater than at A quarry. Such the specific charge has been commonly used at the quarry where hard sandstone has usually been extracted for use as aggregate. Judged from comparatively hard and competent rock exposed on the blast site, the value seems not so great but rather appropriate at least wholly. However, if seen partially, there was a disturbed portion as will be described latter. Thus, the portion only may have become of over-charge.

3.1.3 Stemming

Each hole was loaded with 20 pieces of 3Kiri dynamite, so the charge length on calculation become nearly 6m from its cartridge length (31cm/piece), and thus the stemming length become nearly 3m. This stemming length seems too short compared to that applied in general bench blasting. The (stemming length/burden length) ratio is 1.0–1.65 commonly. Most commonly, it seems 1.0 or a little more. Incidentally, the ratio is 3m/4.5m = 0.65 on calculation.

A loading test with explosive cartridge on the site after the incident found that the actual loading length with 20 pieces of cartridge in the case of hole filled fully with water approximately corresponded with a length calculated from the cartridge length and its numbers and thus in-hole charge length after loading was hardly decreased by the action of buoyancy in water. Meanwhile, that in the case of dry hole was decreased by 20 percent to that on calculation as above. It's more than probable that the loading condition in hole with a minimal amount of water at hole-bottom also is fairly same as that in a case of the dry hole. In that case, its length is assumed to be shortened from 6m to 5m and thus the stemming will become 4m in length which corresponds to (stemming length/ burden length) ratio = 4m/4.5m = 0.90. The stemming length seems not so short although the ratio is under 1.0.

The problem will be in a case where hole is filled fully with water. If there is such a hole, then a required stemming length (at least 4m) should be kept by reducing some number of cartridges in hole. However, such a hole become of a little undercharge whereby, so it will be necessary for the burden or the spacing to be narrowed by just that much, but that will not be practical. If there is a concern about blowing out due to undercharge since the charge is twenty percents less in the hole, it will be able to be defused by making an stemming firmly with an appropriate material and a required length Incidentally, stemming material used on the site was No. 7 crushed stone (2.5-5.0mm).

However, each hole on the blast site seems to have been what have more to less or a minimal water depending on one hole to another, and thus the charge and thus the stemming in loading with 20 pieces of dynamite cartridge seems to have varied in length depending on that. Therefore, it will be essential to check carefully the remaining hole-length

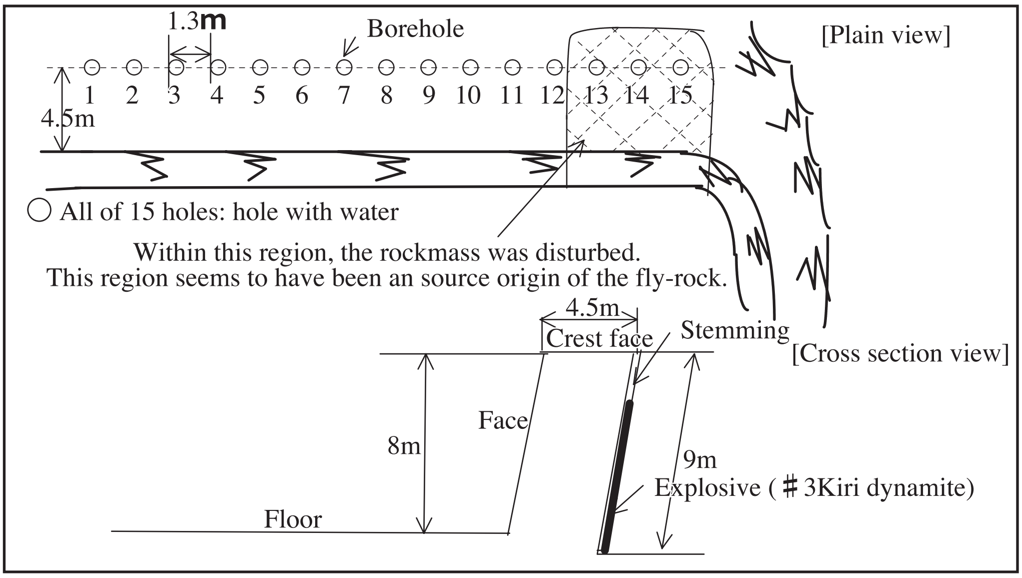

Fig. 4 Schematic representation of the blast pattern at B quarry.

loading with the cartridge in order to keep a sufficient in-hole space required for a required stemming.

3.2 Condition of the rock mass exposing on the blast site and scattering situation of fragments around the site and probable causes for the fly-rock

In a region with No.1 to No.12 hole, the rock mass with hard and competent quality without appreciably joint was exposed on the face and the crest. Fragments piled up in an area of nearly 15-20m as usually ahead of the face in the region, leaving a clear wall. Meanwhile, in a region of No.13 to No.15, many rectangular fissures with some soft inclusion were exposed appreciably on the blast face as if many bricks were stacked there, leaving quite widely unclenched fractures in quite a number of them. Furthermore, a few large rock blocks (nearly 1m in size) rested just in front of the face and large rock lumps were left like plastering down on the face. And furthermore, a number of small rock lumps (nearly 10-15 cm in size) were scattered far (to a distance of approximately 50-60m) beyond there.

Seen from the local condition that the rock mass being disturbed appreciably on the right- hand face (No.13-No.15) as well as that of rock pieces scattering ahead of the face, it's more than probable that explosion gas together with some rock pieces in the vicinity will have blasted out through some widely unclenched fissure (or fracture). However, it will be able to be negated also that (1) there was a variation in minimum burden uncalculated on an uneven face if seen from such the on-site condition, (2) the stemming in some hole came short of length due to any of the reasons as described above, and or (3) such the region became what had a little over-charge if seen from the rock quality, etc.

Or again, any of the above factors may have spurred blowing out of explosion gas together with some rock pieces.

3.3 Technically possible measures to reduce the danger of fly-rock

In order to minimize the danger of fly-rock, the following means will be able to be taken on the basis of some probable causes as described above.

- To carefully check the condition on blast site from all sides. Especially not to overlook any irregularity on the blast geometry such as an unevenness on the face, a dent of the face in front of the hole bottom and an chipping away of the crest, etc.. And to determine the burden and the hole- spacing or the hole-positions taking account of that.
- To pay attention to any change in the rock mass quality (such as existence of high frequent joints or fissures and soft or poor rock with weathering or faults), and to modify the drilling pattern.
- If there is some large void and some crush zone or soft material zone (running to the face) in the hole, to change the charging pattern into such the pattern as adopting stemming deck partially. Still to check carefully the performance and the aspect of cuttings under drilling in order to find out its position in hole.
- If there is a disturbed region with a number of widely unclenched fractures, not to drill or load the hole with explosives there.
- To clear up the delineation of blast geometry, scaling off all loose rocks on a face if there are, and to position each drilling hole correctly on the basis of a fresh face.
- To load with explosive carefully checking such the condition since an existence of water in hole tends to lead to some variation in charge length and thus stemming length. If judged not to be able to keep an in-hole space required for sufficient stemming under loading, then to stop the subsequent loading.

4. The fly-rock incident at C quarry (case 3)

On February 8, 1999, when blasting with holes cross the blast face (i.e. front face) was done by using DS detonators and # 3 Kiri dynamite (31.5kg), some rocks flew nearly 300m away in a left-hand direction of the blast site (or in a parallel direction to the face), and hit a company car, a factory employee under operating it within the factory site and the slate roof of a house within there. This incident at the quarry brought about the following damages. (Fig. 5)

- Human damage:
  A piece of rock crashed through the front glass of a car and then it hit and rebounded upon a driver's door and fell on the right thigh of an employee under operating the car. The degree of injury of the person was a thigh contusion with the complete recovery ten days.
- Physical damage:
  The front glass and the inner globe of driver's door suffer the damage by a piece of rock. And another piece of rock damaged also to a roof on the factory building. An opening (nearly 4cm) with crazing arose on the slate roof.

4.1 Blasting under the fly-rock incident

Blasting was done by the face blasting with holes drilled cross the blast face (or cross the face) at the quarry concerned, where in-hole charge was extremely limited in order to inhibit the blast vibrations at a hospital which was located nearly 50m backward the site. In order to still reduce the vibrations at the position, DS detonators (# 1, # 3, # 5, # 9) with long time and its discrete delay numbers were used.

4.1.1 Blasting pattern (Fig. 6)

Blasting type: blasting with holes cross the front face (i.e., collapse blasting), Type of rock: sand stone
Face height: 7.5m, Hole diameter: 70mm,
Hole diameter: 70mm, Burden to the front face: 3.3m,
Hole length: (upper row) 3.7m, (lower row) 3.7m,
Holes: 14 (upper row) 7holes,(lower row) 7holes
Hole angle: 15°, 10°(respectively, an upper row and a lower row of holes)
Explosive: # 3Kiri dynamite (50mm×750g) 31.5kg,
Cartridge length: 30cm
Detonator: Instantaneous detonator (# 1) 2 pieces,
Decisecond detonator (# 3) 4 pieces,
Deci second detonator (# 5) 4 pieces,
Decisecond detonator (# 9) 4 pieces,
Total 14 pieces

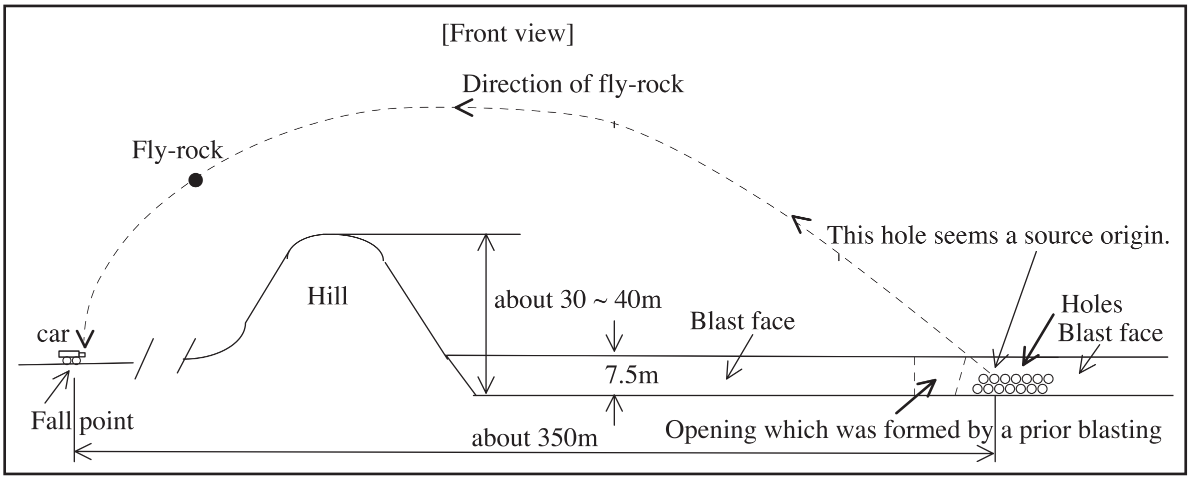

Fig. 5 Schematic representation of fall point and blast site (C Quarry).

4.1.2 Charge length

Each hole was charged with 3 pieces of # 3Kiri dynamite cartridge and stemmed with PE packaged sand in the blasting. In this instance, it could be derived on the calculation from the cartridge length (0.31m/piece) that holes were charged with to 1/4 × hole depth (or 0.93m). In practice, it's inferable that the length became still shortened by tamping rigidly each cartridge within hole. This length is a little different from what have been recommended generally. (i.e., up to 1/3 × hole depth in case of dynamite), but rather seems appropriate on minimizing scattering of rock ahead of the face.

4.1.3 Specific charge

The following equation (2) has been applied to a general collapse blasting. This equation is what was derived out by modifying an equation (1)[4] for the collapse blasting. If the equation is applied to such the face blasting as in this instance, the calculation of specific charge (or blasting coefficient) become as follows.

$$LR = C \cdot Ds \cdot W \cdot H \qquad (2)$$

Where, L : Charge weight per hole (kg) ; 2.25kg
C : Blasting coefficient (specific charge)(kg/m^3)
Ds: Hole spacing (m) ; 2.6m
W: Burden (Distance from the face to the collapse line) ; 3.3m H: Face height (m) ; 7.5m
R: Row numbers (integral number) ; 2rows

$$2.25 \cdot 2 = C \cdot 2.6 \cdot 3.3 \cdot 7.5$$
$$C = 0.07\text{kg/m}^3$$

An observation on the site after the blasting (or the fly-rock incidents) found that major part of the blast site consisted of the rock mass with comparatively hard and competent quality except for a left-hand part of the site where there was a soft zone with quite dense joints. If contrasted to Table 2 that shows a general criterion, this value under the condition of the rock mass seems not too great but rather less. Incidentally, a blaster in charge said that the charge had been limited virtu-

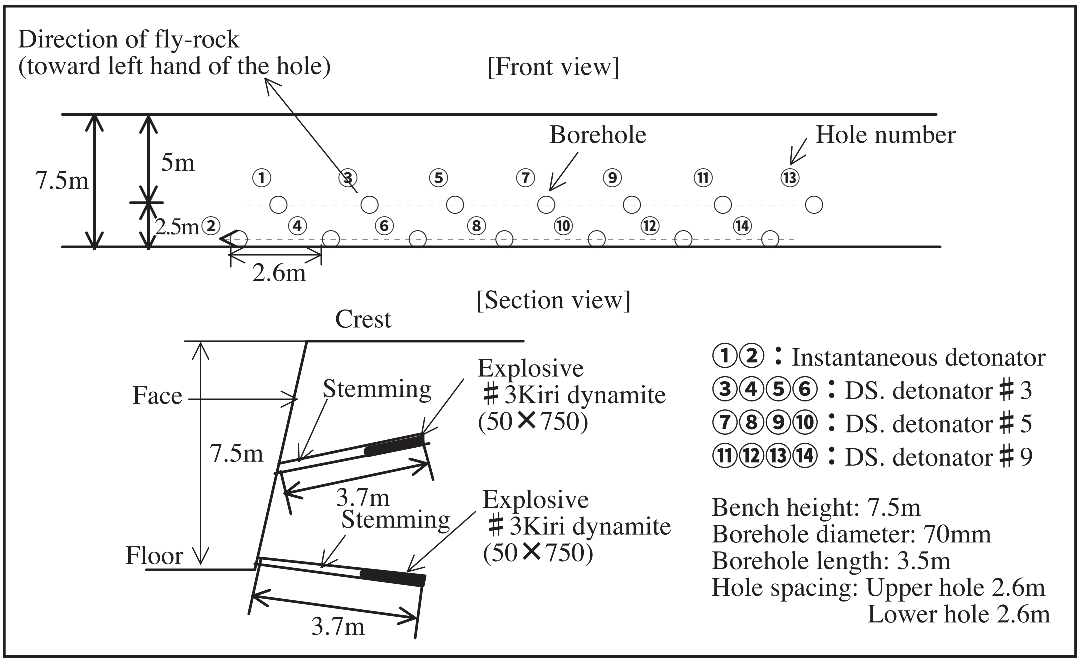

Fig. 6 Schematic representation of blasting pattern at C quarry.

Table 2 Specific charge in collapse blasting (Kg/m^3) [4].

Explosive	Soft rock	Medium hard rock	Hard rock
Dynamite	0.07 ~ 0.09	0.09 ~ 0.14	0.13 ~ 0.20
ANFO	0.08 ~ 0.11	0.10 ~ 0.15	0.14 ~ 0.20

ally to an extent that the rock mass could be loosened since the quarry has faced a severe problem on blast vibrations.

4.2 Condition of the rock mass exposing on the blast site and scattering situation of fragments around the site

An observation on the site immediately after the blasting showed that on the whole rock hardly moved ahead of the blast face and only a small number of fragments piled up right in front of the face. However, a good many small-sized fragments (approximately 10-15cm in size) rested ahead of only the front face closed to the left-hand periphery with (# 1) instantaneous detonator, and a considerable part of the fragments got lying down quite far (to nearly 30m).

And, most holes on the right-hand face with DSD # 3, # 5 and # 9 left quite deep hole-butts. Many fractures also were exposed on the face and some of them were open widely enough to dig up easily by an excavator held in the quarry. And furthermore, it was found that there was an sharp change in rock quality within the region with # 1 holes and # 3 holes. There were less appreciable joints on a right-hand face to the boundary (# 3 side) but quite dense joints developing in every direction on the left hand.(# 1 side).

4.3 View about cause for the fly-rock

As described above, a sharp change in the quality of rock mass was seen on a boundary between a region with #1 holes and that with the other DS #3, # 5 and # 9 holes. That is, the rock mass in the earlier region was what has a soft quality with quite dense joints developing at short intervals in every direction, and on the contrary the rock mass in the latter region had a hard or competent quality without appreciable joint, and many hole-butts with some remarkable depth were left on the face and its depth was such that it proves a hard rock mass.

A blasting way that was applied under the incident was sort of a face blasting with two rows of holes cross the front face like so-called collapse blasting. The specific charge was $0.07kg/m^3$ on calculation that seems not too high but rather a little low in the right-hand region as long as seen from such the on-site condition. By nature, such the type of blasting is likely to propel a number of rock pieces ahead of the face. And, there will be also a great possibility that an explosion gas with some rock pieces blow out ahead of the face due to the under-charge unless a sufficient stemming is done there. Therefore, it will go without saying that great care is to be taken to the direction.

However, really, the fly-rock did not gone toward the front but it went toward a left- side direction of the blast face (or a direction parallel to the front face). The reason will be considered as follows.

After two holes with instantaneous (# 1) detonator was fired, the rock mass in an region surrounding the holes was broken too broadly and then a minimum burden being developed in left-hand direction of hole with # 3 will have been decreased very greatly out of calculation. Alternatively, some fissure in the region may have been extended close to the hole with # 3 and it have been greatly open at that moment. And, when the holes with # 3 were fired, its explosion gas by firing of some hole with # 3 may have blasted out together with some rock-pieces through the fissure. Or, at that time, some cartridge (with detonator) may have been almost in the state like nakedness that led to open firing.

There was also a large opening (nearly 10m in width) just close to the blast site that had been formed by some prior blasting (Fig. 5). A left-hand wall within the opening was to shield such fly-rock. In addition, there was also a hill (approximately 150m in distance, 30-40m in height) between the blast site and the stricken place (approximately 350m). Even so, some fly rocks flew over these two barriers. Probably, the ones will have gone forward with no little angle such as beyond 45°.

A few rock-pieces which got lying down on the stricken place was nearly the same in shape as what scattered far ahead of the face with #1holes (approximately 10-15cm in size).

And still, there was an evidence of a worker belonging to the stricken factory that the blasting at that moment was felt so much loud as that had done usually. That seems to support the blowing out or the open firing as stated above.

4.4 View about firing delay used on the blast site

A combination of instantaneous detonator and DS detonator was used on the blast site. The DS detonators were what has four delay numbers with one jump and two jumps or with 0ms (# 1), 500ms (# 3), 1000ms (# 5), 2000ms (# 9). A reason for which such the long delay interval was applied was for ensuring to separate and thus reducing number-by-number vibrations.

But then, that seems to possess an element of danger. It will be stated as the danger that minimum burden is decreased out of calculation, that open firing occurs due to cut-off (or over-break), and that explosion gas together with any rock-piece blows out through some fracture (or fissure), during a successive firing. The danger will be increased, as the delay interval is made longer. Where there is a rock mass with distinguishingly open fractures, that will be especially so. Therefore, it seems preferable to use as short delay interval as possible in order to decrease such the danger as long as the blast vibrations can be held down to a given tolerable value. And, if there is some boundary with a sharp change in rock quality like in the region with # 1 and # 3 hole, should not the two adjacent holes situated cross the boundary been fired with an identical delay number of detonator?

According to Explosive & rock blasting[5], the rock moves at a rate of 1.5-60m/s (nearly an average of 30 m/s) in a quarry bench. If that is applied to the drilling pattern (Fig. 6) under the incident, the minimum burden will be become nearly 2m in a left-side direction to the # 3 holes (but not in a direction for the front face). And so, supposing that the fragment wall that was formed by an immediately prior firing (prior number of detonator) act as a shield to fly-rock until it displaces to half distance of the burden, an effective delay interval will become below 33ms on calculation. And, considering about the blast pattern, the wall will go to a distance of respectively 15m or 30m on calculation since the interval that were applied there are 500ms or 1000ms. That will be just in a condition as fragments by pre-firing have already piled up or rested on a ground, still leaving many un-firing holes, and then there will be no longer such the fragment wall.

4.5 Possible measures to the probable causes

Some probable causes that led to the fly-rock were considered as described above. If based on the causes, the following will be stated as technically possible means to allow minimizing such the danger of fly-rock.

- To remove any loosened rock on the blast face (the lateral face as well as the front face) and to clear up the blast geometry thereby, and to fix an appropriate position of each hole on the basis.
- To carefully check the on-site condition if there is a sharp change in the rock quality or the geological condition on there.
- To fire mutually adjacent holes situated cross the boundary with an identical delay number of detonators, if there is an explicit boundary between a poor rock mass (i.e. extremely soft rock mass with dense joints etc.) and a hard rock mass on the blast site.
- To control each in-hole charge or hole spacing depending on the rock quality and the geological condition.
- To stem rigidly with a sufficient amount of stemming material so that in-hole charge may not be flicked out during a successive firing.
- To allocate an optimum delay to each hole. To that end, to select an appropriate type of detonators (MS or DS) and its delay numbers.

As long as blast vibrations are kept below a tolerable value, as short delay interval as possible will be to be applied in order to minimize such the danger to fly-rock as well as allow the good fragmentation in such the type of blasting as the collapse blasting. However in practice, it seems desirable to carry out some blasting tests on this site beforehand in order to determine such the type of detonator and its delay required.

5. Summary

The inspection at three quarries found that the round did not seem of over-charge on the whole but a certain hole or a certain part on the blast site seems to have become a source origin of the fly-rock, and the possible causes were stated as follows.

- A sharp change in the rock quality like a soft material, many dense joints, a widely open fracture and etc. exist locally.
- Drilling deviation
- Existence of in-hole water
- Irregularity of the blast face etc.

In other words, one or more of them will have led to a certain hole varying in minimum burden and thus a region with the hole will have become of over-charge, and alternatively that may have promoted the explosion gas blowing out through some fissure. In order to minimize such the danger of the fly-rock, the suitable means depending on them will have to be provided as described in more depth in this paper.

In addition, the author would like to mention especially the following based to the inspections about three incidents.

Even if in-hole charge and total charge were was respectively 2.25kg and 31.5kg and the both were slight like at C quarry, some rock-pieces actually flew to a no less than nearly 350m long distance. And no fly-rock flew in front of blast face but in a parallel direction to the face. That seems to have been just a case that was hardly anticipated under normal circumstances.

Therefore, blasting workers on such the quarry site will be to catch sharply any change in on-site condition (such as some soft rock mass with dense joints, some disturbed rock mass with many fractures, some irregularity on the blast face and etc.) and thus to make a well-thought-out modification to the blasting (e.g. hole position, in-hole charge and firing delay, etc.) depending on the change. And some precaution will have to be taken more suitably. Still, either worker in charge of blasting seemed an expert with abundant knowledge and experience that was cultivated on the site until now. Needless to say, in order to minimize the danger of fly-rock, the blasting has to be performed steadily based to them, but for that the blasting work will have to be done with room sufficiently. Still for that, a mutual understanding and close cooperation relation between a person in charge of blasting work and the one in charge of the subsequent loading and hauling work etc. is required, and above all the quarry manager's recognition about that will be indispensable.

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