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Blast Design for Improvement of Limestone Fragmentation

Piyush Rai[1) and Hyung Sik Yang[2)

석회석 파쇄도 향상을 위한 발파 설계

피유시 라이, 양형식

Abstract The paper presents a case study of a limestone quarry of the Philippines, where major problems in terms of improper fragmentation, poor wall control, and poor heave of the muck pile were witnessed. The paper highlights the significant role of switching over from diagonal firing pattern to V-type firing pattern, and also of making suitable adjustments in the stemming column length for improved confinement and gas retention. The study revealed that by making aforesaid design modifications in the blast round, marked improvement in blasting results was registered. Looking at the results, it was further contemplated to expand the mesh area in the subsequent blast rounds. The mesh area was incremented from the existing 8.96 m^2 to 12 m^2. The results were meticulously registered in the field, and clearly depicted definite improvements in the blast results in terms of increased P.F., reduced boulder count, reduced FEL cycle time, reduced dozing hours and improved heave.

Key words Fragmentation, Indirect method, Blast design, V type firing pattern

초 록 이 논문은 필리핀 석회석 광산에 적용한 연구 결과로서 이 광산에서는 파쇄석 입도분포가 좋지 않고 벽면의 유지나 파쇄석 더미의 분산이 불량하였다. 기폭패턴을 대각선 방식에서 V 타입으로 바꾸고 전색장을 조정하여 저항과 가스압의 유지기간을 향상시켰다. 이를 통하여 발파결과가 향상되었다. 특히 공당발파영역이 넓어진 것으로써 그 성과를 확인할 수 있다. 공당발파영역은 기존의 8.96m^2에서 12m^2로 넓어졌다. 화약계수는 증가하였고 대괴의 수는 감소하였으며, 전방적재기의 행정시간이 감소하였다. 또 공전 시간이 줄었으며 적재 높이가 향상되었다.

핵심어 파쇄도, 간접평가, 발파설계, V 형 기폭

1. Introduction

Firing pattern provides a pathway for detonation wave in order that explosive charged in the holes can be initiated. In any blasting program, the foremost requirement is sequential generation of free face (with the blast progression). To this end, the firing pattern decides the movement and direction of rock by creating free face for subsequent blast holes/rows. Extensive works have been reported by various researchers namely, Smith (1976), Hagan (1983) and Rai (2002) on different types of firing pattern (row to row, diagonal, V-type etc.). The researchers suggest that each firing pattern has its own application. Proper use of pattern vis-à-vis the blast requirements can provide optimal blast performance in terms of fragmentation, throw, wall control etc. This is attributed to the importance of

1) Currently, Visiting Professor, Dept. of Energy & Resources Eng., Chonnam National University, Korea & Associate Professor, Dept. of Mining Eng., Banaras Hindu University, Varanasi, India.
2) Professor, Dept. of Energy & Resources Eng., Chonnam National University, Korea.
* 교신저자 : hsyang@jnu.ac.kr
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firing burden in any blast round. By changing the firing pattern, the firing burden and thereby the ratio of spacing to burden is also subject to change (Rai & Baghel, 2004; Oliver, 2003).

Stemming, the upper portion of blast hole which has been packed with inert material such as drill cutting, aggregates etc. confines and retains the gases produced due to the explosion inside the blast hole. Confinement and retention promotes the rock fracturing by transmitting a major portion of shock as well as gas pressure through the broken rock mass prior to the release of stemming.

Improper confinement results not only in wastage of energy and poor fragmentation but also in environmental problems such as air blast, fly rocks, etc. (Chiapetta & Wyciskalla, 2004; Mclonghlin, 2004). According to Brinkmann (1990), almost 50% of explosive energy is lost if premature venting is allowed to occur through the collar region of blast hole. Floyd (1999) indicated that improper explosive confinement due to inadequate stemming produces over sizes in the face and perimeter zones of any blast round.

The length of stemming is a function of many variables. Excessive stemming causes increased stiffness accompanied with excessive confinement resulting in to host of problems. Rai (2002) reported excessive boulders in the blasted muckpile, especially from the collar zone due to excessive stemming. Based on their extensive studies, various researchers to name just a few of them, Ash (1973), Rzhevsky (1985), Konya (1996) etc., proposed the length of stemming column as function of either hole diameter or bench height or burden for optimum breakage in the bench blasting.

Nevertheless, the thumb rules and the governing equations seem to really work provided the integrity of stemming column is maintained during the blasting sequence. To this end, the present case study highlights the importance of plugging the stemming column along with making changes in firing pattern and the mesh area (SxB) for improving the blasting results and evaluating the fragmentation by indirect methods.

2. Objectives and Research Methodology

The main objective of research programme was to achieve suitable fragmentation with good throw and drop (heave characteristics) so that the blasted muck could be easily loaded by Front-End-Loaders (FELs). It may be worth mentioning here that the poor diggability feature of the FELs call for good fragmentation within the muck pile along with its proper heave, in order to facilitate the loading operations.

In the light of this problem, the author of this paper was requested upon to improve the productivity of the FELs by attempting suitable changes in the blast design parameters in order to increase the production as well as productivity from the quarry. Hence, keeping the importance of the problem the author visited the field to diagnose the problem areas and harp upon the ways to resolve them. The following were the major observations of the author, which formed the basis for the changes incorporated in the blasting practice:

1. Diagonal firing pattern was not able to provide the requisite fragmentation, and, even the desired throw.
2. Large size boulders occurred inside the muckpile.
3. FEL was over assisted by dozer because of coarse fragments inside the tight muck piles, which, resulted into unwanted escalation in the dozing costs.
4. Irregular final wall profile after excavation of the blast.

In order to fulfill the research objectives many full-scale blasts were conducted in the quarry by varying crucial blast design parameters on the limestone benches in the East section of quarry.

Although V-type and diagonal firing pattern provide same effective spacing to burden ratio, the

V-type firing pattern was contemplated to be more suitable for the slated requirements because it increases the opportunity of in-flight collision amongst broken rock fragments during their movement. This particular characteristic of V-type firing was considered important to reduce the fragment size and boulder occurrence within the blasted muck piles. The existing practice of firing 6m high benches on diagonal pattern was registered as baseline data as given in table 1. Thereafter, two blasts were conducted on the same bench on V-type firing, the results of which were also registered as given in table 2.

On observing the success of the V-type firing on 6m high benches, the next level of increasing the bench height from 6m to 9m was tried again with both types of firing (diagonal and V-type). The field observations and results are tabulated in table 2, where B5 blast was conducted on diagonal firing, and, B6 blast was conducted on V-type firing pattern. The pre-existing diagonal pattern and the changed V-type pattern are shown in fig.1 & fig. 2.

Further, to obtain the maximum energy utilization for better heave of the blasted muck, the blast hole plugging was done in conjunction with V-type firing. The plugging was done at the top of the explosive column without making any changes in the stemming column length. On critically evaluating the success of incorporating the aforesaid changes on 3.2mx 2.8m mesh area (SxB), similar changes were attempted on incrementally expanded mesh areas (up to 4.0mx3.0m) in order to authenticate the validity of said changes.

To quantitatively ascertain the improvements in blast performance, the following blast evaluation parameters were closely monitored and recorded in the field on day-to-day basis.

Powder Factor: Powder factor was precisely estimated by properly observing and recording the total number of trucks loaded during the complete excavation of the muck pile. Proper documentation of this data was crucial. Hence, this data was recorded carefully. Total number of trucks was converted into tonnage by use of truck factor, which, in turn, was

Table 1. Field observations and results for baseline and adjusted blasts

S No.	Parameters	B 1	B 2	B 3
1	Hole diameter (mm)	102	102	102
2	S x B (m)	3.2 x 2.8	3.2 x 2.8	3.2 x 2.8
3	Avge.Bench height (m)	6	6	6
4	Avge.Sub-grade drilling (m)	0.5	0.5	0.5
5	Avge.Stemming length (m)	1.8	1.8	1.8
6	No. of holes	21	39	66
7	No. of rows	5	5	6
8	Total Explosive quantity (kg)	613.45	1255.41	2191.02
9	Firing pattern	Diagonal	V-type	V-type
10	Stemming Plug	No	No	No
11	Total weight of limestone broken (te)	1859	4329	8427
12	Powder factor (kg/te)	0.33	0.29	0.26
13	Boulder count	10	7	5
14	FEL cycle time (sec.)	53.23	48.51	37.65
15	Throw (m)	3.50	12.50	14.20
16	Drop (m)	1.80	2.03	5.15

Table 2. Field observations and results for increased bench height

S No.	Parameters	B 4	B 5	B 6	B 7
1	Hole diameter (mm)	102	102	102	102
2	S x B (m)	3.2 x 2.8	3.2 x 2.8	3.2 x 2.8	3.2 x 2.8
3	Avge.Bench height (m)	9.0	9.0	9.0	9.0
4	Avge.Sub-grade drilling (m)	1.0	1.0	1.0	1.0
5	Avge.Stemming length (m)	1.8	1.8	1.8	1.8
6	No. of holes	43	32	44	36
7	No. of rows	4	3	3	3
8	Total Explosive quantity (kg)	2345	1728	2050	1908
9	Firing pattern	Diagonal	V-type	V-type	V-type
10	Stemming Plug	Not used	Not used	In last row	In last 2 rows
11	Total weight of limestone broken (te)	8684	6480	8609	7196
12	Powder factor (kg/te)	0.27	0.27	0.24	0.26
13	Boulder count	40	20	5	0
14	FEL cycle time (sec.)	55	55	50	47
15	Total dozing time(hr)	17	13	13	8
16	Throw (m)	4.5	6.0	8.75	12.10
17	Drop (m)	2.0	2.1	53.50	3.75

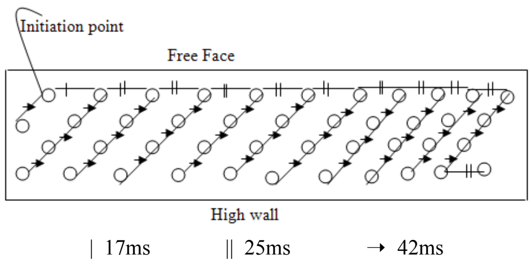

Fig. 1. Diagonal Firing Pattern (not to scale)

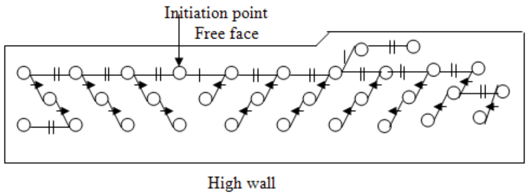

Fig. 2. Modified V-type firing pattern (not to scale)

calibrated by the conveyor weighing machine system. The over sizes, which could not be handled by the FEL, were separated at the bench to be not included in the tonnage computation. The total quantity of explosive actually loaded in the blast round was registered in order to express the powder factor in terms of kg/ton of limestone broken.

Boulder count: Total number of separated boulders from each blast (which could not be loaded by the FEL, being over size) was counted at the face. The maximum feed size of crusher was 75mm.

FEL Cycle time: Several researchers (Kanchibotla, 2001; Rai, 2003; Marton and Crookes, 2000; Singh & Yalcin, 1999) have reported the relationship between diggability of loading machines with respect to degree of fragmentation in the muck pile. Hence, the cycle time of the FELs digging the muck pile was categorically recorded throughout the excavation history such that realistic cycle time data could be taken as an index to the blast performance. Precise stopwatch was used for this purpose.

Dozer performance: To facilitate the loading operation by the loader, dozers are normally deployed in any blasting program. Nevertheless, excessive deployment of dozer (expressed in terms of total dozing hours) is suggestive of poor blasting performance. Hence, the actual number of dozing hours spent by the dozers on a muck pile was also recorded to provide another reliable index to evaluate the blast performance.

Throw and drop measurement: As shown in fig. 3, the throw, drop and lateral spreading of the muck pile are crucial parameters for the success of the FEL operation. Greater throw, drop and spreading may be considered to be favorable for digging of the muck by the FELs. During the fieldwork, throw& drop for each blast was measured immediately after the blast through the tape measurements by taking the offset measurements on blasted muck piles.

3. Field Description

To meet the stated objectives, full-scale blasts were conducted in a limestone quarry in the Philippines. The annual production of the quarry was over 3 million tonne of limestone. The quarry was worked in three sections, namely, West, Central and East. The present study pertains to the East section workings where the limestone beds, separated at 2-3m interval, were dipping at an inclination of 30 to 40 degree. The geology of the deposit was quite difficult owing to frequent shaly and clayey intrusions. The compressive strength of limestone was about40 MPa. The grade varied from 42.5%-52.5%, the cut off grade being 47%. The specific gravity of limestone was 2.4. The East section comprised of seven benches each almost 6-9m high. But there were no significant discontinuities in the bench.

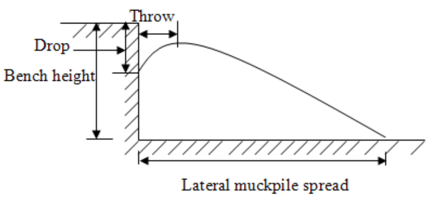

Fig. 3. Throw, drop and muckpile spread

The loading operation was mainly performed by the 5 m^3. FEL. The blasted muck was loaded on 35 and 50 tonne rear dump trucks. As already mentioned, the FELs could not yield satisfactory performance due to the presence of large sized boulders in the tight muck piles. Hence, the dozer and hydraulic breakers were deployed to facilitate the FEL. Further, poor wall control and appearance of back break could also be witnessed. Even with the firing on the diagonal pattern, the heave (throw) was poor.

4. Result and Discussions

A number of blasts were conducted in the quarry to fulfill the stated research objectives. Field observations and the blast performance results are tabulated in tables 1, 2 and 3. All the blast rounds were drilled on staggered drilling pattern with ANFO as explosive and sensitized emulsion cartridges as primer. The blasts were initiated by shock tube system with delay sequencing. Table 1 gives the comprehensive details of three experimental blasts, namely B1, B2 and B3. The blast B1 was conducted on diagonal firing pattern to generate the base line data for the existing firing pattern and blast practices observed by the management.

Key blast evaluation parameters, as already discussed in the previous section, were registered for this baseline blast. A perusal of all these parameters for B1 reveals less powder factor, large boulder count, high cycle time, with poor throw and drop characteristics. Large boulder count naturally increased the cycle time of FEL because considerable time of the FEL was wasted in fighting against these boulders within the muck. This, in turn, also influenced the muck pile spreading (as already dis-

Table 3. Field observations and results for adjusted blasts on expanded mesh area

S No.	Parameters	B 8	B 9	B10	B 11
1	Hole diameter (mm)	102	102	102	102
2	S x B (m)	3.6 x 2.8	3.6 x 2.8	4.0 x 3.0	4.0 x 3.0
3	Avge.Bench height (m)	9.0	9.0	9.0	9.0
4	Avge.Sub-grade drilling (m)	1.0	1.0	1.0	1.0
5	Stemming length (m)	1.8	1.8	1.8	1.8
6	No. of holes	40	28	20	36
7	No. of rows	3	4	3	4
8	Total Explosive quantity (kg)	1942	1280	1009	1836
9	Firing pattern	V-type	V-type	V-type	V-type
10	Stemming Plug	in last row	in last 2 rows	in last row	in last 2 rows
11	Total weight of limestone broken (te)	8846	6007	4977	9495
12	Powder factor (kg/te)	0.22	0.21	0.20	0.19
13	Boulder count	10	5	5	1
14	FEL cycle time (sec.)	50	48	46	46
15	Total dozing time (hr)	7	5	3	2
16	Throw (m)	9.50	12.35	10.35	13.25
17	Drop (m)	3.50	3.75	4.10	4.75

cussed). Due to this the dozer was often deployed to spread the tight muckpile close to the final wall. On the other hand, the blasts B2 and B3 (fired On V-type firing) distinctly reveal the superior results in terms of better PF, reduced boulder count, reduced FEL cycle time and drastically improved in the throw &drop characteristics. However, due to initial operational constraints the dozing hour records could not be gathered on the blasts B1-B3. The reason for these significant improvements was on the lines as envisaged and already discussed in the preceding section. It is further noteworthy that with the given change in the firing pattern, the size of the blasts (B2 andB3) could also be increased substantially.

Looking at the significant improvements in the blast performance, the diagonal firing and V-type firing were again conducted after on the benches with bench height of approximately 9m in the East section. The results of Blast B5 again indicate significant improvements owing to adoption of V-type firing pattern on higher benches (9m) also. Reduction in the boulder count (20 nos.) and total dozing hours (13 hrs.) along with increase in the spreading of the muck pile due to increased throw (6 m) and slightly increased drop value could be clearly observed while comparing the blast B5 with B4. These improvements clearly indicate the improvement in the fragmentation within the muckpile. However there was no reduction in the FEL cycle time due to certain lapses in the planning of dozer operation. Further, the powder factor for both the blasts was identical. From the post- blast and post-excavation site investigations, the presence of prominent fractures, especially along the collar region of these benches, was observed. Hence, venting off phenomena was suspected, which, was substantiated by the occurrence of large sized boulders from the collar region of these blasts.

To overcome the problem of collar over sizes, the stemming region confinement was contemplated and implemented in the blasts B6 and B7 with stemming plugs in last row and last two rows respectively without changing the length of stemming column, and, also without changing the mesh area (SxB). A post blast result distinctly indicates the combined success of V-type firing along with the adjustments made in the stemming by incorporating the stemming plugs. Significant improvements were observed in terms of boulder count (5 nos.), cycle time (50 sec.), throw (8.75 m), drop (3.50 m) and spreading of muckpile. Here it is consequential to mention that although PF (0.26) is higher for B7 the dozing hours (5 hrs.) and the throw (12.10m) for this blast provide favorable result with no end breaks, to offset the explosive costs.

From the results of these changes, it may be interpreted that, as envisaged earlier, the V-type firing provides better collision opportunities due to which fragmentation within the muckpile is improved with less boulder count. Further, the blast hole pressure confinement for longer duration (due to integrity of stemming plug for longer duration) led to better heaving of the blasted muck with negligible collar over sizes. Further, the absence of end breaks in these blasts authenticates these interpretations.

Nevertheless, during the field observation with the aforesaid modification, it was experienced that the fragment size was unnecessarily reduced (5-20 mm) to almost powdery consistency. Hence, it was contemplated to better utilize the explosive energy by taking the advantage of reduced bench stiffness (bench being 9 m high) by expanding the mesh area incrementally. Two blasts (B8 & B9) were conducted on slightly increased mesh area of 3.6x 2.8 m while keeping all the parameters same as in B6 & B7. Looking at the results of PF, as anticipated, a marked reduction in the PF value (0.21) was witnessed for both the blasts. The boulder count, cycle time, throw and drop values remained almost consistent, whereas, dozing hours reduced substantially. As with blast B6 & B7, the blasts B8 & B9 also did not reveal any end breaks. Being encouraged with the success of the results obtained from B8 & B9, further expansion of the mesh area was attempted keeping other design parameters same. All the results from the two blasts (B10 & B11) were quite favorable and further improved over the blasts B8 & B9. Powder factor (0.19) showed significant improvement. Other parameters namely, cycle time, dozing hours, throw, and drop values also revealed marked improvement.

5. Conclusions

Following conclusions may be derived from the discussions:

1. The indirect evaluation methods are of great consequence in small-scale quarry blasts and pave the pathway for improvement.
2. Shift in firing pattern from diagonal to V-type has been effective in improving the fragmentation, reducing the boulder count and also improving the throw, drop and spreading characteristics of the muckpile.V-type firing in combination with stemming plug has been able to retain the blasthole pressure for longer duration, which, in turn, seems to further increase the heaving characteristics of the blasted muck.
3. Due to better fragmentation and heave of the muckpile, the extensive use of dozer (to assist the FELs), was reduced significantly. The performance of loader in terms of reduction in cycle time was markedly enhanced and explosive consumption was significantly reduced. Nevertheless, the stemming plugs are costly, and, hence, their usage calls for judicious planning based on categorical interpretation of the results, which is a site-specific feature.

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References

1. Ash, R.L., 1973, The influence of geological discontinuities on rock blasting, Ph.D. thesis, Univ. of Missouri, Missouri, USA.
2. Brinkmann, J.R., 1990, An experimental study of the effects of shock and gas penetration in blasting, Proc. 3rd Int. Symp. on Rock Fragmentation by Blasting, Brisbane, Australia, pp. 55-66.
3. Chiapetta, R.F. and J.L. Wyciskalla, 2004, Bottom-hole and multiple power decks, *Quarry Management Journal*, pp. 21-30.
4. Floyd, J.L., 1999, Explosive energy relief -The key to controlling over break, Proc. Int. Conf. Explo '99, AusIMM, Kalgoorlie, WA, pp. 147-153.
5. Hagan, T.N., 1983, The influence of controllable blast parameters on fragmentation and mining costs, Proc. 1st Int. Symp. on Rock Fragmentation by Blasting, Lulea, Sweden, pp. 31-51.
6. Kanchibotla, SS., 2001, Optimum blasting? Is it minimum cost per broken rock or maximum value per broken rock?, Proc. Explo-2001, AusIMM, Hunter valley NSW, pp. 35-40.
7. Konya, C.J., 1996, Problems with deck loaded blast holes, E&MJ, pp. 73-74.
8. Marton, A. and R. Crookes, 2000, A case study in optimizing fragmentation, The Aus. IMM Proc. No.1, pp. 35-43.
9. Mclonghlin, M., 2004, Softly softly, World Mining Equipment, Vol. 28, No. 1, pp. 33-34.
10. Oliver, P.H., 2003, Changes to drill pattern and adequate inter-row delay time improve blasting performance, CIM Bulletin, Vol. 96, pp. 60-65.
11. Rai, P. and S.S. Baghel, 2004, Investigation of patterns on fragmentation in an Indian opencast limestone mine, Quarry Management Journal, pp. 21-30.
12. Rai, P., 2003, Change that blast, World Mining Equipment, Vol. 27, No. 9, pp. 43-45.
13. Rai, P., 2002, Evaluation of effect of some blast design parameters on fragmentation in opencast mine, Ph.D. thesis, Banaras Hindu University, Varanasi, India.
14. Rzhevsky, V.V., 1985, Opencast mining unit operations, Mir Publishers, Moscow, 1985.
15. Singh, S.P. and T. Yalcin, 2002, Effect of muck size distribution on scooping operations, J. Int. Soc. Explosive Engineers., V.1, pp. 315-325.
16. Smith, N.S., 1976, Burden rock stiffness and its effects on fragmentation in bench blasting, Ph.D. thesis, Univ. of Missouri, USA.

Piyush Rai
Banaras 대학 광산공학과 Reader
(부교수급)
전남대학교 에너지자원공학과 초빙
교수

Tel : +91-542-670-2509
E-mail : piyushrai_bhu@yahoo.co.in

양 형 식
전남대학교 에너지자원공학과 교수

Tel : 062)530-1724
E-mail : hsyang@jnu.ac.kr