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Arch. Min. Sci. **69** (2024), 3, 391-407

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI: https://doi.org/10.24425/ams.2024.151442

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A FIELD-SCALE INVESTIGATION INTO THE STRATEGIC LOCATION OF AIR DECKS FOR IMPROVED BLASTING PERFORMANCE

Airdeck blasting is a promising technique for improved blast efficiency, reducing explosive consumption, and enhancing fragmentation. Nevertheless, it lacks widespread adoption due to design guideline gaps and differing opinions on air deck placement. This study offers technical guidance based on field experiments to optimise air deck blasting. Full-scale blast experiments were conducted at four distinct limestone benches to evaluate the efficacy of air deck implementation. At Bench-1, experiments were performed using conventional blasting (with full-column charge) and air decks at three strategic air deck positions (i.e., top, mid, and bottom) within blast holes at a selected quarry site. For Benches 2 and 3, comparative fragmentation analyses were conducted between conventional blasts and those utilising air decks positioned in the middle of the explosive column.

Furthermore, the impact of multiple mid-air decks within explosive columns was also evaluated at Bench-4. A comparison of blast fragmentation results revealed that fragments obtained through the air decking technique surpassed those from the full-column charge, regardless of air deck placement. Among the tested air deck positions, the single air deck positioned at the middle of the explosive column yielded superior fragmentation results than other locations. In addition, this technique showed a reduction in explosive charge, back break, and toe-related issues.

Keywords: Air Deck Blasting; Fragmentation; Explosive Charge; Bench Blasting; Mining

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1. Introduction

Blasting operations in the mining industry are crucial in fragmenting rock masses to facilitate excavation. In conventional blasting operations, a continuous cylindrical explosive charge is detonated, which causes fragmentation of the rocks due to the high pressure produced during the explosion process. A shock wave with a high peak pressure propagates outwards in all directions from the blast hole as a compressive stress wave. The compressive stress wave also produces radial cracks in the strata. At the free face, this compressive stress wave reflects as a tensile stress wave. As the tensile strength of the rock is much smaller than its compressive strength, the rock mass breaks at the point where effective tension exceeds the tensile strength of the rock. The high-pressure gas produced by explosive detonation penetrates cracks and enhances rock fragmentation [1]. While conventional blasting is widely used in the mining industry, its environmental impacts, fragmentation control in terms of inconsistent fragment size, excessive overbreak, and limited precision have always remained concerning to industry professionals and the scientific community.

Over the years, significant advancements have been made to improve blasting efficiency with environmental sustainability by optimising explosive energy. Central to these advancements is the strategic placement of air decks within blast holes. The air deck induces a gap in the explosive column, which provides an efficient energy distribution, resulting in better rock fragmentation and blasting cost optimisation and a reduction in environmental effects [1-4]. The utilisation of the air deck blasting technique has also demonstrated significant success in reducing explosive consumption [3-12].

The air decks within the explosive column develop additional compressional shock waves in addition to the primary compressional waves that are produced in the rock mass during blasting. This additional compressional wave is created due to the collision between the two gas streams in the center of the air gap. The collision of the gases generates tremendous pressure at the meeting point and drives the reflected gases to penetrate the fissures, thus aiding fragmentation. In addition, the peak borehole pressure reduces due to wave collision in the air gap. However, simultaneously, multiple impacts of shock waves within the medium are produced due to collision and reflection of gases in the air deck area. This results in 1.5 to 1.7 times more energy being transferred to the medium than when blasting a conventional continuous charge.

Hence, improved rock fragmentation can be achieved by providing an air gap in the explosive column of a blast hole [13].

Experiments to study fracture networks conducted on the Plexiglas model supported Melnikov's theory and demonstrated that a shock wave reaching the stemming is reflected to strengthen the stress field [14]. Marchenko [15] observed a 50% increase in explosive energy utilisation for the breakage of the rock and an improvement in the degree of fragmentation. Jhanwar and Jethwa [16] also concluded that air deck blasting results in better fragmentation and improved utilisation of explosive energy. Furthermore, many other studies found that the degree of fragmentation from air deck blast holes was better than that from conventional blast holes with solid air decks [3,8,9,12,17].

The air decking technique also reduces the cost due to decreased explosive consumption. Thote and Singh [18] showed that the powder factor decreased using the air deck blasting technique. Chiappetta [8] observed that the drill hole with an air deck used 17% to 25% less explosive than that consumed with a solid charge. Moreover, air deck blasting was also found to be more effective in very low to low strength moderately jointed rocks than medium strength highly jointed rocks [19].

The precise location and number of air decks within an explosive column are of critical concern for researchers, and their opinions remain divided on this issue. Researchers and practitioners commonly employ three air deck positions: the explosive column's top, middle, and bottom. However, due to various reasons, a consensus on the air deck position does not exist. Based on numerical simulations, Liu and Katsabanis [20] suggested that placing air decks at mid or bottom positions rather than at the top does not yield production blasting benefits. Other researchers [21-22] found that the middle position of the air deck resulted in improved rock fragmentation. Contrarily, Chiappetta [8], while conducting field-scale experimentation, found that the bottom air deck could be used more effectively than the cylindrical charges because it can produce 2 to 7 times more pressure at the bottom of the hole. The bottom air deck position also effectively overcame the toe problem [23].

Aside from the location, the length of the air deck within an explosive column is also a significant consideration for researchers and industry professionals. Hayat and Tariq [24] utilised a 10% volume of the explosive column as air deck volume for a bottom air deck, while Moxon [21] employed a 30% air deck volume. The former is considered very low, while the latter is regarded as very high [11]. The principal author of this study performed a series of experiments to find the optimum position and length of the air deck using homogeneous concrete blocks [17]. It was suggested that an air deck length equivalent to 20% of the blast column length provides the best fragmentation results for a mid-air deck position at the laboratory scale.

In a nutshell, the air decking technique has received wide acceptance from the scientific community. However, there is a lack of confidence about its adaptability in the industry practice due to the divided opinions of researchers on various aspects of air deck placement, including its location, volume, and influence on fragmentation size distribution. This is mainly due to the lack of comprehensive field-scale investigations, which are essential to provide confidence to industry professionals and a better understanding of the outputs to the scientific community. This study is dedicated to demonstrating the applicability of the air decking technique by involving full-scale field experiments at limestone quarry sites. A total of ten sets of experiments were performed in relatively homogenous limestone deposits possessing almost similar attributes as that of the experimental blocks used in the previous study [17]. The research is focused on finding the best position for the air deck in the blast hole to achieve optimal fragmentation while considering environmental and economic factors.

2. Research methodology

2.1. Blasting sites

This study conducted field-scale blasting experiments at two quarry sites, featuring four selected benches. Ten blast sets were executed in total. Three benches (Bench-1, Bench-2, and Bench-4) were blasted at the DG Khan Cement factory quarry. This site is situated at a latitude of 32°43'53"N and a longitude of 72°48'46"E, near Khairpur village along the Kallar Kahar-Choa Saidan Shah Road, approximately 12 km southeast of Kallar Kahar, District Chakwal, Punjab, Pakistan. The plant site lies within the mountains of the eastern salt range in the Chakwal district of Punjab, Pakistan. Bench-3 was located at the Askari Cement site in Nizampur, District Nowshera, Khyber Pakhtunkhwa, Pakistan, positioned at a longitude of 72°02'00" N and a latitude of 33°47'30"E.

2.2. Geology of the experimental sites

The experimental sites belong to Pakistan's salt range area, which rises out of the Punjab alluvial plains and forms remarkable gorges, scarps, and hill slopes. Three main formations are present within the D.G. cement area (namely, Nammal, Sakesar, and Chorgali). Among these, the Sakesar formation comprises relatively homogeneous limestone with subordinate marl. The formation exhibits a cream to light grey colour, characterised by its nodular appearance with a considerable amount of chert in the upper part [25]. As this formation is massive and homogeneous compared to other formations, a significant portion of the experimentation in this research was conducted in the Sakesar formation.

The geology of Askari Cement Nizampur consists of limestone from the Lockhart Formation. This deposit, ranging from 10 to 200 metres in thickness, exhibits grey to light grey and is characterised by medium-bedded nodular structures with minor amounts of grey marl [25]. A part of this research work's experimental field scale blasting has been carried out in this formation.

2.3. Experimental setup

A group of four relatively homogeneous limestone benches were selected to conduct field-scale experimentation. Three benches (Bench-1, Bench-2, and Bench-4) were selected at D.G. Cement, Chakwal, while one bench (Bench-3) was selected at Askari Cement factory, Nizampur, for the said purpose. Field experimentation at Bench-1 was carried out using a single air deck placed at three different positions of the explosive column, i.e., top, mid, and bottom. In comparison, Bench-2 and Bench-3 were selected for mid-air deck positions only. Bench-4 was selected to carry out experimentation using multiple mid-air deck positions. Full-column charge was also blasted at each bench for reference.

2.3.1. Experimental scheme for single air deck in the blast holes at Bench-1, 2, and 3

Four sets of blasts were designed at Bench-1. Thirty-two holes, each with a diameter of 110 mm, were drilled in a single row. The drill hole pattern at Bench-1 is shown in Fig. 1(a).

The first blast set, consisting of the first eight holes from the left side of the row, was blasted conventionally without air decking. The remaining holes were blasted with a 20% air deck length of the explosive column, and the position of the air deck was also varied, i.e., top, middle, and bottom. The second set consisted of the next eight holes; from the right end, hole numbers 25 to 32 were blasted with 20% air deck length at the middle of the explosive column. The third set with the next eight holes, 17 to 24, was blasted with 20% air deck length at the top of the explosive column. The fourth set with the remaining eight blast holes 9 to 16 was blasted with 20% air deck length at the bottom of the explosive column, as shown in Fig. 1(a).

Full-scale blasts were conducted on two sets, each with 20 blast holes at Bench-2. Set 1 consisted of a conventional full-column charge (without air deck), while set 2 consisted of blast holes with a 20% air deck length of the explosive column placed in the middle of each explosive column shown in Fig. 1(b). All other design parameters were kept constant for both sets.

Thirty-two holes were drilled in a single row at Bench-3, as shown in Fig. 1(c). Similar to Bench-2, the blast patterns constituted two sets. The first set, consisting of sixteen holes, was

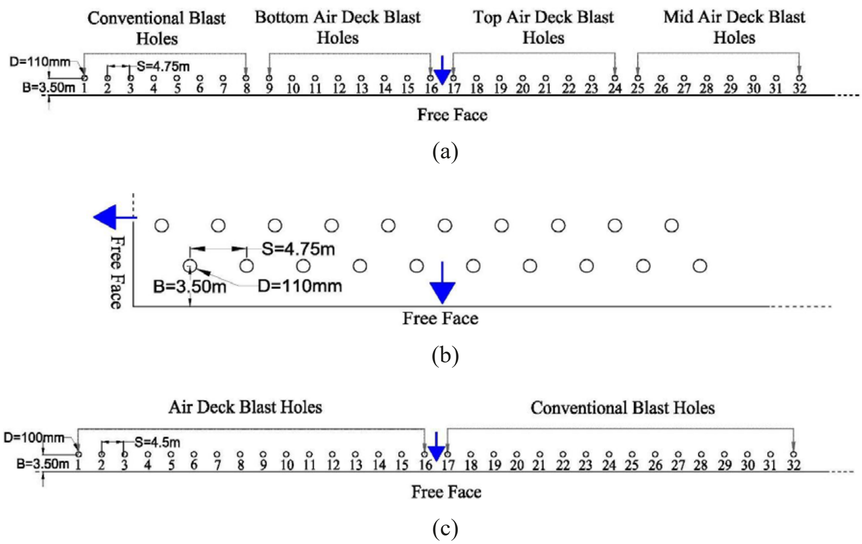


Fig. 1. Drill hole pattern at the (a) Bench-1 (b) Bench-2 and (c) Bench-3

blasted with a full-column charge without air decking, while the second set of sixteen holes was blasted with an air deck equivalent to 20% of the explosive column placed in the middle of the explosive charge.

To introduce an air deck, a wooden plug was introduced as a spacer in the explosive column to create an air space equivalent to about 20% of the explosive charge length. This air deck was placed in the middle, top, and bottom of the explosive column, which reduced the amount of explosive by 20% as compared to conventional blasts with continuous charge. The dimensions of the wooden plugs used in the experimental Benches are shown in Fig. 2.

The loading scheme of each blast hole in Bench-1 for the conventional blast with full-column charge is shown in Fig. 3(a). The loading schemes for the mid-air deck, top-air deck, and bottom-air deck blasting sets of Bench-1 are shown in Figs. 3(b), 3(c), and 3(d), respectively. Similarly, loading schemes for the full-column charge and mid-air deck blasting sets of Bench-2 are shown in Figs. 3(e) and 3(f), while those of Bench-3 are shown in Figs. 3(g) and 3(h), respectively. High explosives, dynamite, and water gel were used as bottom charge and blasting grade ANFO (Ammonium Nitrate: 94%, Fuel Oil: 6%) as column charge in each blast hole. Charge loading was done by putting a dynamite or watergel cartridge attached to the Nonel detonator as a primer charge, followed by cartridges of water gel to make the bottom charge, as shown in Fig. 3. One cartridge of water gel, cut in three equal parts, was used as a booster in the column charge. The drilling pattern employed for each blasting set featured a 3.5 m burden (B) and 4.75 m spacing (S) at Bench-1 and 2, as depicted in Figs. 1(a) and 1(b), respectively. At Bench-3, a drilling pattern with a 3.50 m burden and 4.50 m spacing was utilised, as illustrated in Fig. 1(c).

The firing pattern for the full-column charge, the top, and the bottom air deck positions for Bench-1 is illustrated in Fig. 4(a), while the pattern for the mid-air deck position for Bench-1 is depicted in Fig. 4(b). The firing pattern for full-column charge blast holes and mid-air deck blast holes for Bench-2 is shown in Figs. 4(c) and 4(d), respectively. The firing pattern for both

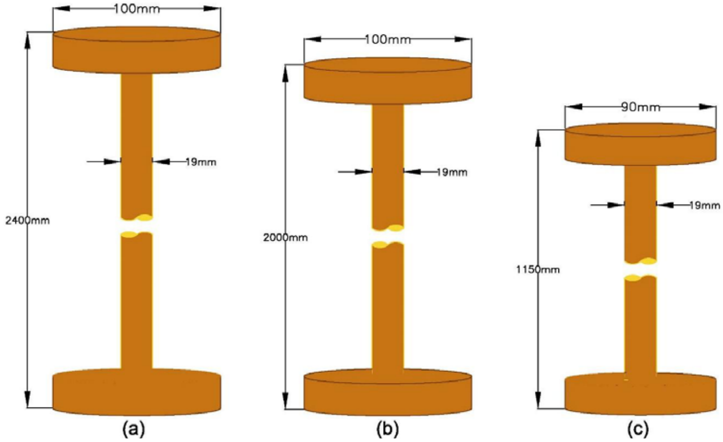


Fig. 2. Wooden plugs used as a spacer in (a) Bench-1 and Bench-2 (b) Bench-3 (c) Bench-4

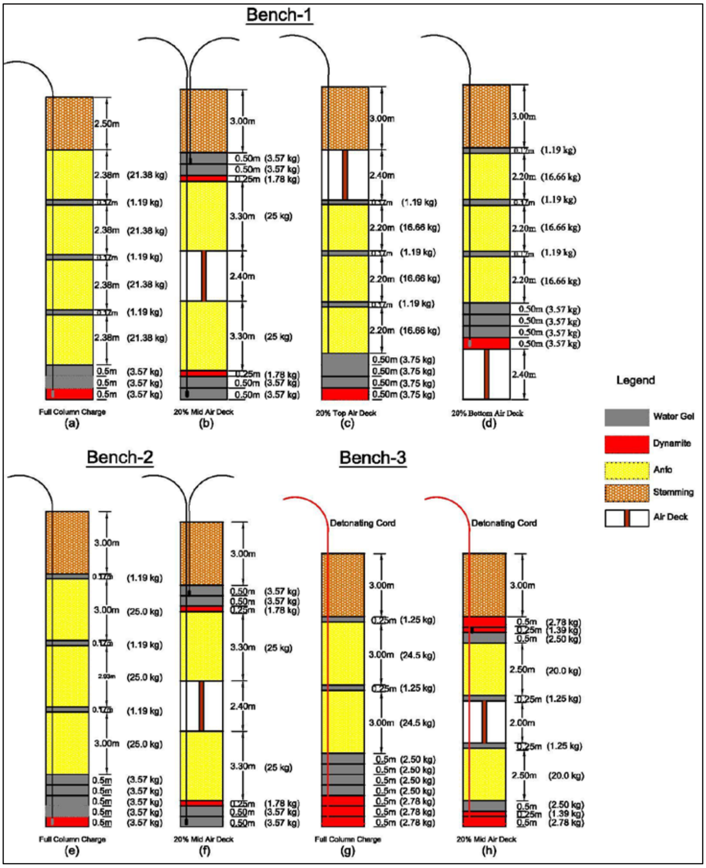
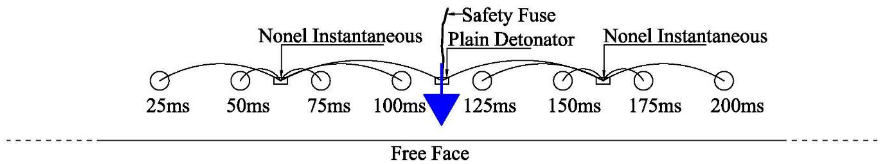
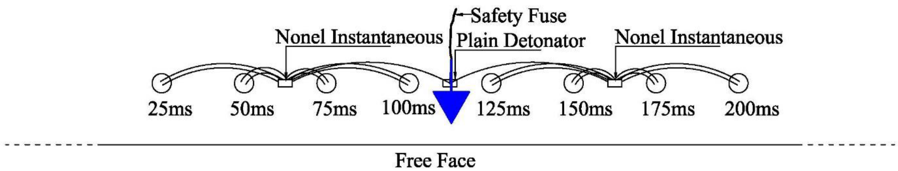


Fig. 3. Loading scheme of blast holes at Bench-1 (a-d), Bench-2 (e-f), and Bench-3 (g-h)

full-column charge and mid-air deck blast holes was kept the same for Bench-3, as shown in Fig. 4(e). The Nonel initiation system was used at Bench-1, 2, and 4, while the detonating cord was employed to initiate the blast holes at Bench-3. A progressive firing pattern was used, and a time delay of 25 ms was maintained after each hole was blasted using an in-hole Nonel delay detonator at Bench-1, 2, and 4. All the blast holes were connected to instantaneous Nonel deto-



(a)



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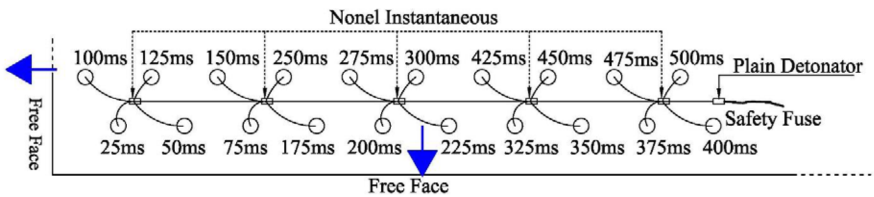
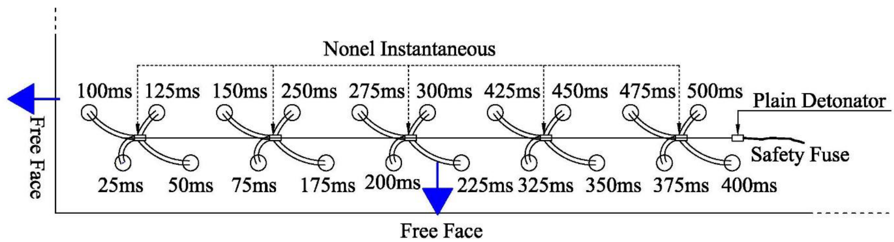
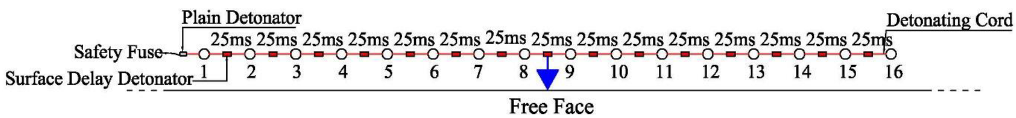


(c)



(d)



(e)

Fig. 4. Firing pattern for Bench-1: a) full-column, top and bottom air deck, b) mid-air deck; Bench-2: c) full-column, d) mid-air deck; and Bench-3: (e) both full-column and mid-air deck positions

nators joined to the plain detonator. The plain detonator was crimped to a safety fuse, as shown in Fig. 4(a-d). In the case of Bench-3, a 25 ms delay was maintained after each hole was blasted using surface delay detonators, as shown in Fig. 4(e).

2.3.2. Experimental scheme for multiple mid-air decks in the blast hole at Bench-4

A total of 16 boreholes were blasted at Bench-4 in two sets, each comprising 8 holes for conventional and multiple mid-air deck blasts, as shown in Fig. 5. For multiple mid-air-deck blasts, two air deck lengths equivalent to 20% of the explosive column in each blast hole were used. The burden (B) and spacing (S) for both conventional and multiple mid-air deck blast sets were kept the same (B = 4.0 m, S = 4.5 m), as shown in Fig. 5.

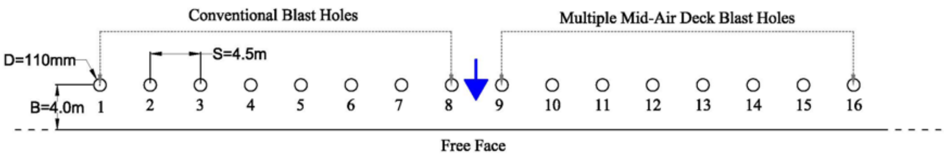


Fig. 5. Drill hole pattern at the experimental Bench-4

The loading scheme of the boreholes with full-column charge and the multiple mid-air decks is shown in Figs. 6(a) and 6(b), respectively. High explosives, dynamite, and water gel were used as bottom and primer charges. Blasting grade ANFO, as in Bench-1, was used as a column charge in each blast hole. One cartridge of water gel, cut in three equal parts, was used as a booster in the column charge shown in Fig. 6.

To provide a cumulative air space equivalent to 20% of the explosive column at Bench-4, two wooden plugs of 1.15 m length were introduced in the explosive column of each blast hole, as shown in Fig. 2(c). The firing pattern of full-column charge and multiple mid-air deck positions for Bench-4 are shown in Figs. 7(a) and 7(b), respectively. Similar to Bench-1, the Nonel initiation system was also deployed at Bench-4, employing a progressive firing sequence with a time delay of 25 milliseconds. Each blast hole was connected with instantaneous Nonel detonators and a plain detonator. The plain detonator was securely crimped to a safety fuse, as illustrated in Fig. 7.

2.4. Fragmentation analysis

To analyse the fragmentation after the blast, several images were taken from an appropriate distance of the blasted muck pile in a proper light environment with a Canon digital camera having a resolution of 3456 pixels. Digital fragmentation analysis software Split Desktop was then used to determine the size distribution of the fragments. This software assists the user in adequately scaling the images. The fragments in each image are automatically delineated, and the size distribution of the rock fragments is determined. The images were cropped before being used in the software to remove all the unwanted background information.

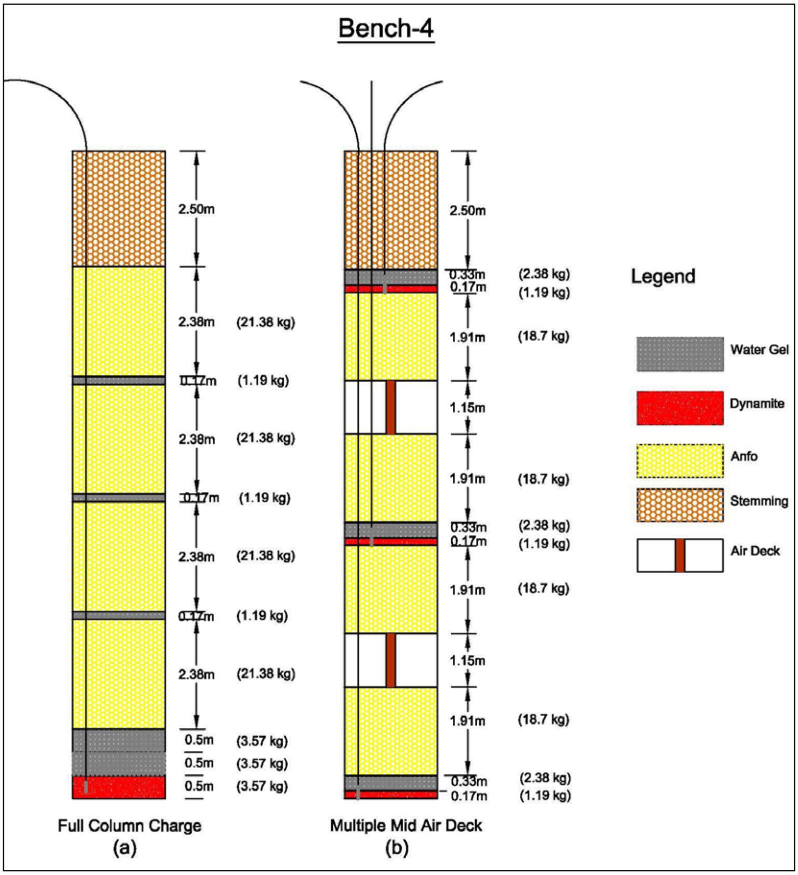


Fig. 6. Loading Scheme of blast holes at Bench-4 with (a) full-column charge and (b) with multiple mid-air deck positions

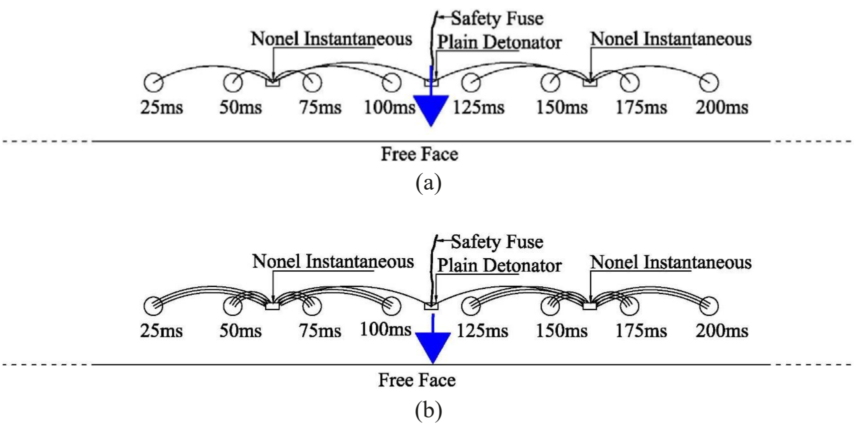


Fig. 7. Firing pattern for Bench-4: a) full-column charge b) multiple mid-air deck

3. Results and discussion

The fragmentation obtained at Bench-1 with conventional, mid-air, top-air, and bottom-air deck blasting sets is shown in Fig. 8(a-d), and their digital fragmentation analysis is shown in Fig. 9.

(a) Fragmentation of full-column charge holes after blasting at Bench-1

(b) Fragmentation of 20% mid-air deck blast at Bench-1

(c) Fragmentation of 20% top air deck blast at Bench-1

(d) Fragmentation of 20% bottom air deck blast at Bench-1

Fig. 8. Comparison of fragmentation of full-column charge blast and 20% air deck placed at various locations in blast holes at Bench-1

It is evident from Fig. 9 that the air deck, when placed at the middle position of explosive charge, produces a small size distribution compared to that produced by full-column explosive charge and air deck at the top and bottom positions. Moreover, 50% average fragmentation passing was achieved at 3.93 inches with a 20% mid-air deck, 14.93 inches with a solid charge, 4.61 inches with a 20% top-air deck, and 11.16 inches with a 20% bottom-air deck blast.

The increase in fragment size reduction with 20% mid-air deck blast as compared to conventional blast was approximately 74% for F10 to F50 passing size, 73% for F60 passing size, 72% for F70 passing size, 70% for F80 passing size, 68% for F90 passing size and 65% for top size.

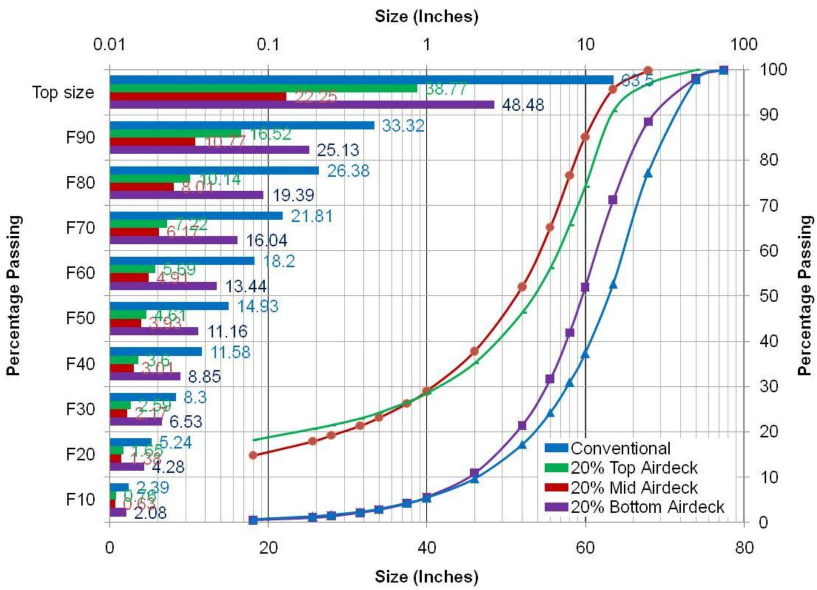


Fig. 9. Comparison of % passing size distributions for conventional and 20% air deck lengths at various positions within the explosive column at Bench-1

The fragment size reduction with 20% mid-air deck blast as compared to 20% top air deck blast was approximately 17% for F10 passing size, 16% for F20 to F40 passing size, 15% for F50 passing size, 14% for F60 passing size, 15% for F70 passing size, 21% for F80 passing size,35% for F90 passing size and 43% for top size was observed.

Similarly, the fragment size reduction with 20% mid-air deck blast as compared to 20% bottom air deck blast of approximately 70% for F10 passing size, 68% for F20 passing size, 67% for F30 passing size, 66% for F40 passing size, 65% for F50 passing size, 63% for F60 passing size, 62% for F70 passing size, 59% for F80 passing size, 57% for F90 passing size and 54% for top size was observed.

The analysis showed that when placed in the middle position of an explosive column, the air deck produced more uniform blasted rock size distribution, with minimum fines and oversized material, compared to those produced with full column charge and when the same air deck length and explosive loadings were used at the top and bottom positions. This finding is because when the air deck is placed in the middle position, it creates multiple series of shock waves, which lead to the efficient transfer of explosive energy in the surrounding rocks.

Moreover, no back break or toe problem was found with a 20% mid-air deck blast at Bench-1. The degree of muck pile formed by fragmentation of the blast with 20% air deck at the middle of the explosive column was better than that produced by the conventional blast with controlled throw, and the scattering of material was also non-existent to make it easy for the loading equipment. The more significant aspect was that in the air deck blast, 20% less explosive was used.

The fragmentation obtained at Bench-2 with conventional blasting is shown in Fig. 10(a), while that of mid-air deck blasting is shown in Fig. 10(b). The digital fragmentation analysis for both blasts is shown in Fig. 11.

(a) (b)

Fig. 10. Comparison of full-column charge blast fragmentation and 20% mid-air decks at Bench-2

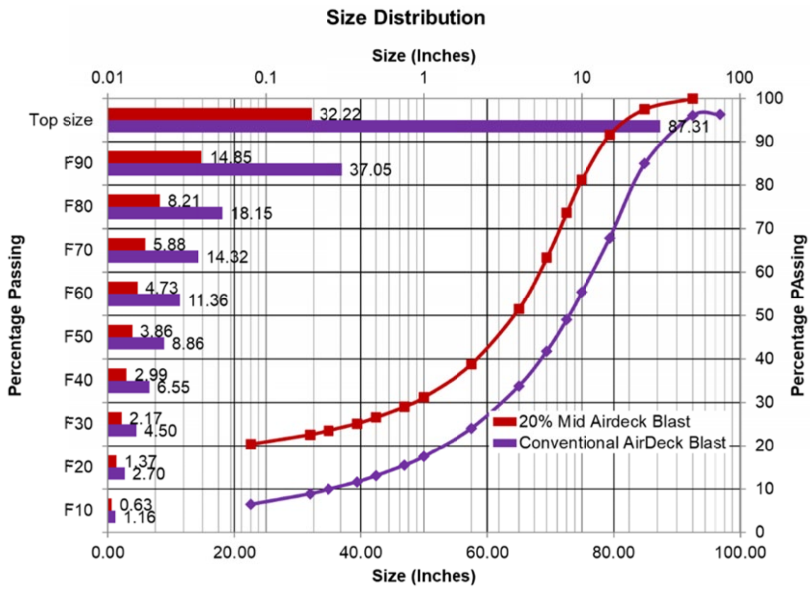


Fig. 11. Comparison of percentage passing of fragmentation of conventional and mid-air deck blast for different sieve sizes at Bench-2

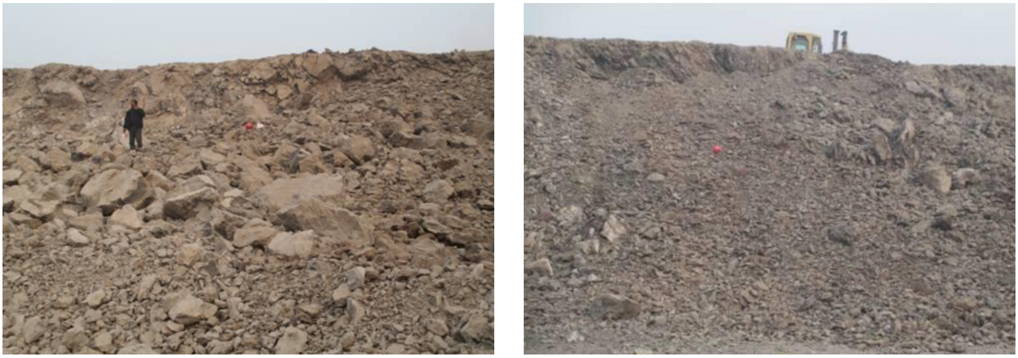
It is observed from Fig. 11 that 20% of the air deck when placed in the middle position of the explosive charge, produces a small fragment size distribution compared to that produced by a full-column explosive charge. Moreover, the average 50% passing of fragments at 3.86 inches with 20% mid-air deck and 8.86 inches with conventional blast was achieved.

The fragment size reduction with 20% mid-air deck blast as compared to conventional blast of approximately 45% for F10 passing size, 49% for F20 passing size, 52% for F30 passing size, 54% for F40 passing size, 56% for F50 passing size, 58% for F60 passing size, 59% for F70 passing size, 55% for F80 passing size, 60% for F90 passing size and 63% for top size was observed.

Mid-air deck produced even fragmentation with no oversized boulders, and conventional blasts with full-column charge produced uneven fragmentation with a significant number of boulders requiring secondary blasting. It was also worth noting that the mid-air deck used 20% less explosive.

Fig. 12 shows the fragmentation obtained at Bench-3 with conventional blasting (Fig. 12a) and mid-air deck blasting (Fig. 12b). Fragmentation results of the Bench for conventional and 20% mid-air deck blast are shown in Fig. 13.

It can be observed from Fig. 13 that the blast with 20% air deck length when placed at the middle position of explosive charge, produced a small and uniform fragment size distribution as compared to the blast when a full-column explosive charge was used. Moreover, 50% passing



(a) (b)

Fig. 12. Comparison of fragmentation of full-column charge blast and 20% mid-air decks at Bench-3

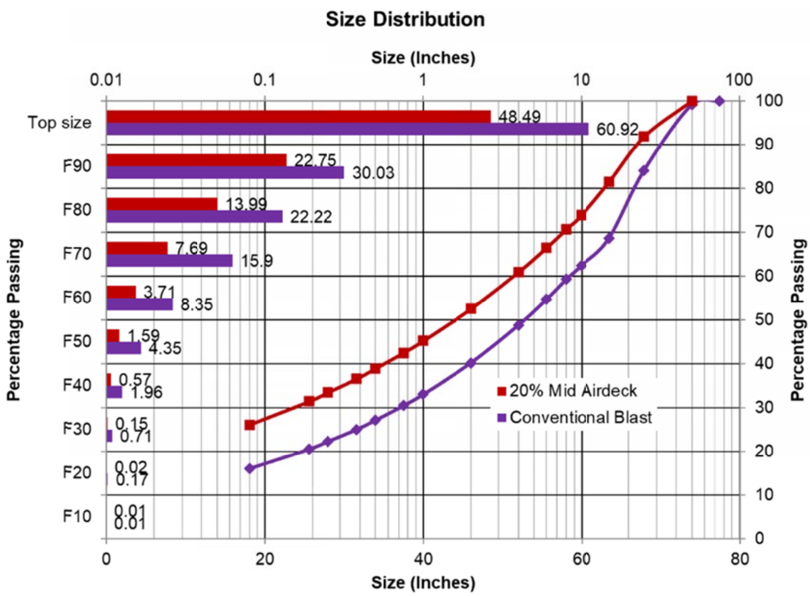


Fig. 13. Comparison of percentage passing of fragmentation of conventional and mid-air deck blast for different sieve sizes at Bench-3

of fragments was achieved at 1.59 inches with 20% mid-air deck blast and 4.35 inches with the conventional blast.

It is also observed that in 20% of mid-air deck blasts, the fragment size reduction of approximately 88% for F20 passing size, 79% for F30 passing size, 71% for F40 passing size, 63% for F50 passing size,56% for F60 passing size,52% for F70 passing size, 37% for F80 passing size, 24% for F90 passing size and 20% for top size was found. Thus, no significant difference was found for sizes of F10 or below.

Fig. 14 shows the fragmentation obtained at Bench-4 with conventional and multiple mid-air decks, and a comparison of each % age passing size of fragmentation for conventional and 20% multiple mid-air decks is further shown by a bar and cumulative percentage passing graph in Fig. 15.

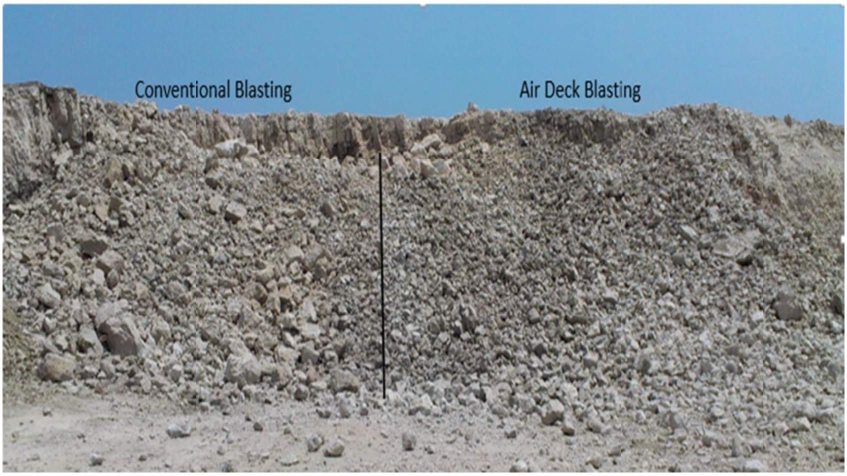


Fig. 14. Comparison of fragmentation of full-column charge blast and 20% multiple mid-air decks at Bench-4

It can be seen from Fig. 15 that placing the air deck at multiple mid positions of the explosive charge creates a smaller size distribution compared to using a full-column explosive charge. Moreover, the average 50% passing of fragments was achieved at 13.55 inches with 20% multiple mid-air deck and 19.25 inches with solid charge.

The fragment size reduction with 20% multiple mid-air deck blast as compared to conventional blast (full-column charge) of approximately 1% for F10, 16% for F20, 27% for F30, 28% for F40, 30% for F50, 34% for F60 to F70 passing size, 42% for F80 passing size, 43% for F90 passing size and 33% for top size was observed as shown Fig. 15.

A comparative fragment size analysis for mid-air and multiple mid-air decks in Sakesar limestone was carried out for Bench-1 and Bench-2 with Bench-4 by the bar, and cumulative percentage passing results are shown in Fig. 16. Bench-3, being located in different lithologies, was excluded from this analysis. It may be observed that when an air deck is placed at a single mid position of the explosive column, it produces smaller size fragmentation than the two air decks placed at two different mid positions of the column charge. The average 50% passing of fragments was achieved at 3.93 inches with a mid-air deck at Bench-1 and 13.55 inches with

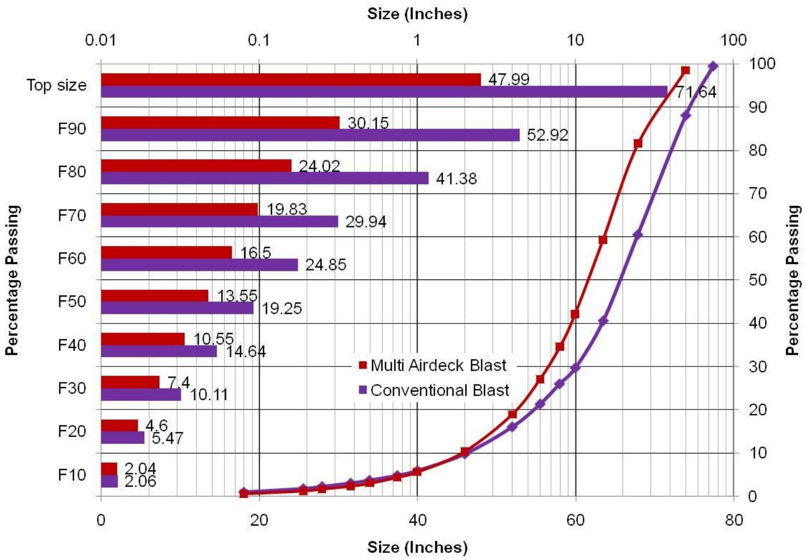


Fig. 15. Comparison of percentage passing of fragmentation of conventional and multiple mid-air deck blast for different sieve sizes at Bench-4

a multiple mid-air deck for Bench-4. The fragment size reduction with the 20% mid-air deck blast as compared to multiple mid-air deck blasts of approximately 69% for F10, 70% for F20, 71% for F30 to F50, 70% for F60, 69% for F70 67% for F80, 64% for F90 passing size and 54% for top size was observed as shown Fig. 16. A similar fragment size distribution was observed for single mid-air deck blasting at Bench-2, in which the average 50% passing of fragments was

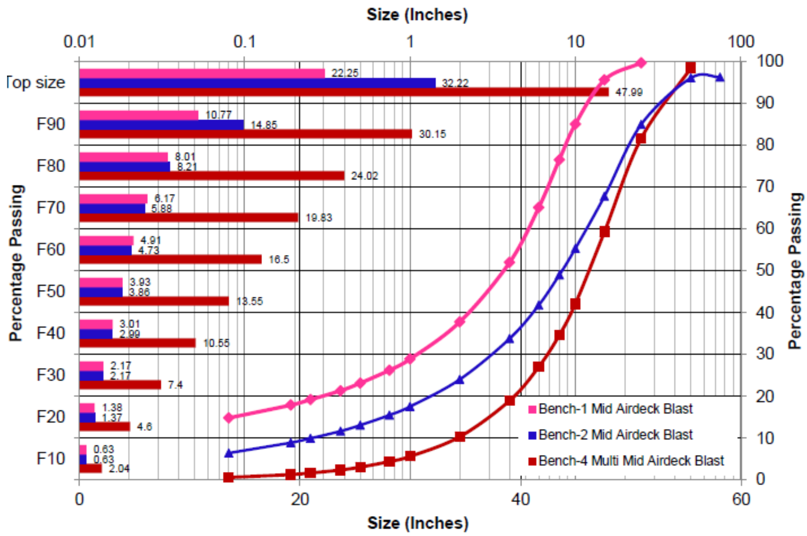


Fig. 16. Comparison of percentage passing of fragmentation of mid-air deck and multiple mid-air deck blasts

achieved at 3.86 inches with a mid-air deck compared to 13.55 inches with a multiple mid-air deck blasting at Bench-4. The analysis revealed a similar fragment size reduction of approximately 69% for F10, 70% for F20, 71% for F30, 72% for F40 to F50, 71% for F60, 70% for F70, 66% for F80, 51% for F90 passing size and 33% for top size was observed as shown Fig. 16.

Hence, a single air deck equivalent to 20% of explosive length produces better fragmentation than when two air decks with a combined volume of 20% were placed at two locations in the middle of the explosive columns.

4. Conclusions

Field-scale experimentations were carried out to investigate the best position of the air deck in the explosive column to achieve optimum fragmentation. The full-scale tests were performed on four relatively homogeneous limestone benches. One bench (Bench-1) was selected for a single air deck placed at three different positions, i.e., Top, mid, and bottom. Two benches (Bench-2 and Bench-3) were selected for blasting using mid-air deck positions. In addition, multiple mid-air deck blasting was performed at bench 4. Conventional blasting with full-column charge was also performed at each bench for reference. The major conclusions drawn are as follows.

- Analysis of the blasted fragmentation results showed that 20% air deck length at the top, middle, and bottom of the explosive column produced better fragmentation than when a conventional blasting method was employed with a full-column charge without any air deck.
- It was evident that 20% of air decks when placed in the middle position of the explosive column, produced a more uniform blasted rock size distribution than those produced at other positions or with a full-column charge without any air deck. Moreover, no back break and toe problems were found with 20% of mid-air deck blasts. The degree of muck pile formed by fragmentation of the blast with a 20% air deck at the middle of the explosive column was better than that produced by a conventional blast with controlled throw, and the scattering of material was also non-existent to make it easy for the loading equipment. Another significant aspect was that 20% less explosive was used in the air deck blast.
- Regarding the multiple air decks, double air decks, equivalent to 20% of the explosive column when placed in the middle of explosive columns, achieved improved fragmentation compared to conventional blasts with full-column charge. However, a comparison of a multiple mid-air deck with a single mid-air deck shows that the single mid-air deck provided better rock fragmentation than multi-mid-air decks.
- Hence, this study recommends using a single air deck equivalent to the 20% column charge when placed in the middle of the explosive column. It produces better blast performance, giving good fragmentation, muck pile, and throw while reducing back break and toe problems.

Acknowledgment

This research was supported by the University of Engineering and Technology Lahore, Pakistan

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