DURGACHARAN PANIGRAHI*, SATISH KUMAR SINHA**, GARIB NATH SINGH***

A STUDY INTO OCCURRENCE OF FIRE IN OPENCAST WORKINGS OVER DEVELOPED COAL PILLARS AND EVOLVING CONTROL PARAMETERS FOR ITS SAFE EXTRACTION

BADANIE PRZYPADKU WYSTĄPIENIA POŻARU W WYROBISKACH ODKRYWKOWYCH PONAD UDOSTĘPNIANYMI FILARAMI WĘGLOWYMI I OPRACOWANIE PARAMETRÓW KONTROLNYCH DLA ZAPEWNIENIA ICH BEZPIECZNEGO WYDOBYCIA

In India, a number of opencast mines are being worked over the coal pillars developed by underground bord and pillar method of mining. In these cases, the fires have occurred in most of these opencast mines causing loss of the coal reserve, production, productivity and safety.

In this research work, 13 such mines have been studied over a period of three years and critical parameters for occurrence of these fires have been identified. This paper presents the details of observations for two such mines and detailed statistical analyses have been carried out by using confidence interval (C.I.) and analysis of variance (ANOVA-Two-way classification) for finding out the range of these critical parameters which can be controlled to reduce the occurrence of these fires.

Keywords: Opencast over underground bord and pillars, critical to fire, mining parameters, critical review, mine operational parameters, confidence interval (C.I.) and analysis of variance

W wielu kopalniach odkrywkowych w Indiach wydobycie prowadzi się w wyrobiskach ponad filarami ochronnymi udostępnianymi przy wykorzystaniu metody filarowo-komorowej. W takich warunkach powstające często w kopalniach pożary powodują utratę zasobów węglowych, zmniejszenie wydajności i poziomu wydobycia oraz negatywnie wpływają na bezpieczeństwo pracy.

W artykule tym przeanalizowano przypadki 13 kopalni odkrywkowych na przestrzeni trzech lat, zidentyfikowano krytyczne parametry dla określenia możliwości wystąpienia pożaru. Artykuł przedstawia dokładne obserwacje poczynione w dwóch kopalniach, poparte szczegółową analizą statystyczną z zastosowaniem przedziałów ufności i analizy wariancji (ANOVA – klasyfikacja dwukierunkowa) do określenia wartości parametrów krytycznych w celu zminimalizowania ryzyka wystąpienia pożarów.

Słowa kluczowe: prowadzenia odkrywki powyżej filarów podziemnych udostępnionych metodą filarowo-komorową, parametry krytyczne określające możliwość wystąpienia pożaru, parametry górnicze, przegląd krytyczny, parametry związane z wydobyciem, przedział ufności, analiza wariancji

*   INDIAN SCHOOL OF MINES, DHANBAD – 826004, INDIA
**   RESEARCH SCHOLAR, INDIAN SCHOOL OF MINES, DHANBAD – 826004 & SENIOR FACULTY, MINING, INDIAN INSTITUTE OF COAL MANAGEMENT, RANCHI – 834006, INDIA. Corresponding Author: e-mail: sinhasatish@hotmail.com
*** DEPARTMENT OF APPLIED MATHEMATICS, INDIAN SCHOOL OF MINES, DHANBAD

1. Introduction

Prior to 1972-73, i.e. before nationalization of Indian Coal Mining Industry, mostly coal mines were operated by small private mining companies. These companies were interested to operate these mines by bord & pillar method, which was not capital intensive. As a result, many coal seams lying at a shallow depth were mostly developed by the same method. Because of the shallow depth, the depillaring of these developed seams could not be undertaken (Singh, 2013). After 1972-73, these seams standing over developed pillars were required to be extracted for working of lower seams. The only method which could be adopted was opencast mining of these pre-developed seams. Thus opencast mining over developed pillars was adopted at a number of places in India and in most of the cases; active fires have been encountered during these mining operations.

The authors of this paper have carried out extensive investigation in last five years to find out the causes of these fires, so that ameliorative measures can be taken to control it. It is expected that the findings of this study will provide introspection to the international community to control fire in such a situation and operate the mine for achieving the targeted production and productivity with safety.

This paper presents a few live cases of these fires, analysis of parameters affecting the occurrence of fire and the painstaking steps taken to reduce or prevent the occurrence of these fires.

The finding of the paper will not only provide the guidance for safe opencast mining over the developed seams but also for mining of seams which are very prone to spontaneous combustion.

It may be mentioned here that this type of opencast mining activity is spreading across India throughout the coalfield namely Jharia Coalfield, Raniganj Coalfield, Bokaro Coalfield, Wardha Valley Coalfield, Godavari Coalfield etc. There are a number of mines in each of these coalfield. However, authors have studied 13 such opencast mines such as Kusunda, Shatabdi, Ena, Rajapur, Bhowra and North-South Tisra in Jharia Coalfield, SonepurBazari in Raniganj Coalfield, Ramagundam and Yellandu in Godavari Coalfield, Sirka in South Karnpura Coalfield, Selected Dhori Q-III in East Bokaro Coalfield, Chirimiri Opencast Mine in Chirimiri Coalfield, and Ghugus in Wardha Valley Coalfield spreading over the whole country (Singh, 2013).

Out of these 13 cases, the observations of the two mines, namely Ghugus in Wardha Valley Coalfield and Shatabdi in Jharia Coalfield are briefly presented in this paper.

There are reasons for selecting these mines. It may be noted that Ghugus Opencast mine is operated in developed coal seam "Mayo" and the fire is very active during the mining operation. Sometimes the fire is very active and it disturbs the mining operation. At times there is no or minimal fire in these developed seams. Therefore the fire is very cyclic in nature.

There is another mine Mungoli Opencast Mine which operates on the virgin part of the same "Mayo" seam in its strike direction and the most striking feature is that there is no fire in this opencast mine.

In the second case presented in the paper is Shatabdi opencast mine, which was actively under fire and the parameters causing this intense fire, were identified and suggested to the mine management for implementation of the findings of the observations. These findings were implemented and now there is no fire in the mine.

These two typical cases may help and facilitate the readers of the paper to understand the parameters affecting the fire which can be prevented by taking suitable actions in the field. These observations have also been corroborated by other cases in the rest of the aforementioned 13 mines worked under the similar situation.

2. Field observations from mines

2.1. Ghugus Opencast Mine, Wardha Valley Coalfield, India

Underground mining in Ghugus was started in 1915, developing Mayo Seam of about 20 m thick in three sections. Each of these sections is of 3-5 m in thickness with parting in between. Some part of the lower section has been depillared with hydraulic stowing. Extent of underground workings in strike direction was 3600 m while in dip, it was 1400 m.The maximum depth of workings had reached up to 176 m from the surface (Vijh, 1995).

The opencast mining over this developed seam was started in the year 1984 with Shovel-Dumper combination. The overburden of 35-40 m from the rise side is being extracted in three prominent benches. The first two benches from the top are of 8m height and being extracted by deep hole drilling and blasting method with Shovel-Dumper combination.

The third and the last overburden bench was of 24 m height is extracted by Dragline with 24 m^3 bucket capacity and 96m boom length. The cut width for dragline bench was around 40 m in 2009 and subsequently it was increased to 70 m for increasing production of the mine from 1.5 to 1.9 million ton per year (Mty). The average stripping ratio of the mine is 1:5. The bench height is 20 m in coal and it is same as the coal seam thickness. A portion of the plan of Ghugus opencast mine is presented in Figure 1. The dimensions of cut width 70 m, exposed face length of 270 m and the position of shovel operation, nearest and farthest end of the face are shown in Figure 1.
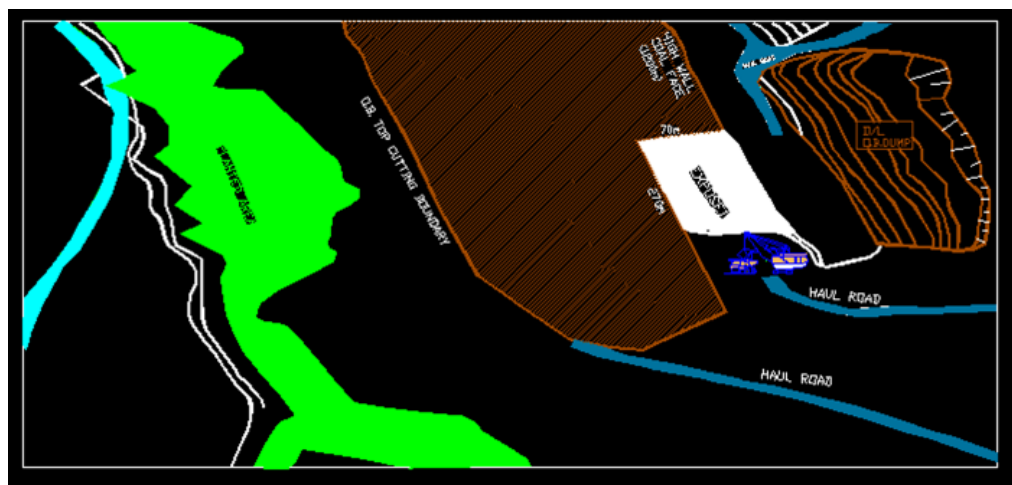

Fig. 1. A portion of plan of Ghugus Opencast Mine and equipment deployed at coal face

A study of earlier reports on the occurrence of mine fire clearly reveals that the fire in the first case, i.e. at Ghugus Opencast Mine operating in Wardha Valley Coalfield, was started because the overburden was removed and the coal bench was kept exposed for a long time before the machines were commissioned on the bench for final coal extraction.

1148

Since then the fire continued in the mine affecting production, productivity and safety. The first observation in the mine by the authors was started in the month of April 2009. The three years long observation on occurrence of fire in this mine, reveals the following:

- The fires have started mostly from the gallery mouth exposed on the high wall side of the bench and in most of the cases; it was getting converted into blazing fire. To corroborate this observation, a photograph showing the position of fire in the high wall side of bench is presented in Figure 2.
- Near to the coal production area of the bench, the numbers of blazing fires from the gallery mouth are less and along the strike, occurrence of fire increases. To substantiate the observation, Figures 3 and 4 are reproduced.

Fig. 2. Position of fire in the high wall side of the bench

Fig. 3. High wall side near to the coal production area

Fig. 4. High wall at the farthest end from the coal production area

Figure 3 clearly depicts that immediately ahead of the production area, there is no or less fire. However, there is blazing fire at the farthest end of the face, which is indicated in Figure 4. It has been observed that from the nearest point of face operation, the fire gradually increases and it reaches the peak intensity at the farthest end. This is mainly because of long exposure

period of the high wall side before being extracted. This will happen to both ends of the face in the strike direction in a cyclic manner. This will directly depend upon the rate of face advance.

- The third important observation is that extent of fire is limited to maximum of two pillars inside towards dip from high wall side of the bench (Panigrahi, 1996). The two affected pillars keep shifting as the face moves on along strike. It may be mentioned here that the initial size of pillar was 25 m × 25 m centre to centre. Two pillars, i.e. up to 50 m are affected which is extracted along the cut width during the movement of the face. Once the high wall is exposed, the fire starts again from there and by the time it is reaching to two pillars, it becomes dormant. This cycle is repeated and as a result the fire is not spreading throughout the mine in dip direction.

- The fourth important observation is the perception of the mine management that the fire is mainly occurring because of the high susceptibility of coal to spontaneous heating. To verify this hypothesis, a coal sample from the developed seam had been collected and the intrinsic properties as well as susceptibility to spontaneous heating have been studied. It has been observed that coal seam contains high volatile matter (VM), 45.5%, and moisture (M), 10.48% and its susceptibility to catch fire measured by its crossing point temperature (CPT) is 133°C. The aforementioned high values of VM and M coupled with low CPT (<140°C) are the main responsible factors for high susceptibility of coal to spontaneous heating. The mine operators may not have much control on these intrinsic parameters.

It may be mentioned here that during this long observation period of 3 years, it could be found that in some cases, intensity of fire in the opencast mine reduces during certain span of time and during the same year it intensifies at other span of time.

In addition, the same Mayo seam in a virgin patch is extracted in a nearby mine, Mungoli and there is no fire present in this particular mine as shown in Figure 5.

Fig. 5. Mungoli Opencast Mine in Wardha Valley Coalfield

The aforementioned observations do not supplement the hypothesis that fire occurring in Ghugus Opencast Mine is because of proneness of seam to spontaneous heating only.

However, a closure observation of the production activity of the mine reveals that the mine planned for the production target of 1.9 million tonnes per year had been approved by Ministry of Environment & Forest, Government of India and this was the maximum production; the mine management could produce from this mine. As soon as its target was achieved, the mine had to be kept idle for last few months of the year. During the idling period, intensity of the fire has been found to increase to a very significant extent. Therefore, it may be concluded that the occurrence of fire depends upon the progress of the coal face to a large extent rather than the proneness of the coal seam. The intensity of the fire problem in this mine increases with reduction in the rate of coal face advance. It may be mentioned here that with the resumption of coal production, the intensity of fire subsequently reduced to a great extent as depicted in Figure 6.

Fig. 6. Highwall of Ghugus Mine during active production phase

2.2. Shatabdi Opencast Mine, Jharia Coalfield, Dhanbad, India

Shatabdi Opencast Mine is located in Jharia Coalfield and is working a combined seam (V/VI/VII) 24 m in thickness. This has been developed in three sections by bord and pillar method. Subsequently the developed pillars are being extracted by opencast method since 2001-02. The mine has been facing serious fire problems since 2004-05.

A glimpse of the fire problem from the opencast mine site is presented in Figure 7.

The mine has got a strike length of 200 m and its cut width is 35 m. The coal bench exposure in strike direction is kept minimum due to occurrence of fire.

The field observations have been carried on in the mine for a period of four years and the salient features of these are as follows:

- The fire is very active which is evident from Figure 7. The mine management had given up hope earlier to operate this mine successfully.
- They were of the impression that the coal is very susceptible to spontaneous heating and could not be addressed properly.

Fig. 7. Fire problem in Shatabdi Opencast Mine during 2004-05

- The coal sample are collected from the working benches and basic parameters like volatile matter(VM),moisture(M) and crossing point temperature(CPT) are determined and the values are 16.2%,0.9% and 177°C respectively. These data clearly reveal that the coal has very less VM & M and its CPT being very high (more than 160°C); therefore the coal is least susceptible to fire.
- Another opencast mine, namely Block-2, being worked in the same combined seam over developed pillars at a distance of 5 km from this mine, do not experience much of a fire problem. The coal characteristics data regarding low susceptibility of coal towards fire corroborates well with least occurrence of fire in Block-2. Shatabdi Opencast Mine was producing coal in the range of only 0.4 to 0.6 million tonnes per year (Mty) where as in Block-2 opencast mine, the mine was producing 2 mllion tones per year.
- Critical analysis of the observations reveal that because of low production at Shatabdi, the coal face movement was slow aggravating fire activity which was fairly absent because of high production and fast movement of face in Block-2 mine.
- The mine management was convinced that if the production at Shatabdi Opencast Mine is increased, it would facilitate faster movement of the coal face that may lessen the fire problem.
- With sustained persuasion, the mine management increased the production of the mine to 1.8 million tonnes per year in the year 2011-12.
- As a result, the intensity of fire got subdued during 2011-12 as evidenced from Figure 8.
- Thus the fire problem in the mine could be controlled by maneuvering the coal bench parameters facilitating faster rate of face advance to meet enhanced production target and at the same time reducing the exposed area of coal.

Fig. 8. Shatabdi Opencast Mine during 2011-12

3. Analysis of field observations and selection of critical parameters causing fire

Finally deriving the experience from two major case studies presented in the paper, i.e. Ghugus and Shatabdi Opencast Mines, together with the brief experience of "Mungoli" and "Block-2" Opencast Mines, the following conclusions may be drawn. The fire problem in opencast mines working over developed coal galleries are mainly governed by two important and controllable parameters, which are as follows:

i) Total area of coal exposed to air, and
ii) Rate of coal face advance

Similar observations have also been made in other thirteen mines studied in this research work. The aforementioned two parameters may be termed as the parameters critical to fire (CTF). These two parameters are analysed in greater details to develop further understanding of this problem.

3.1. Total Area of Coal Exposed to Air

Figure 9 indicates the concept of total area of coal exposed to air while working over developed galleries by opencast method. The total area consists of "Apparent area" and "Additional area". Apparent area is the area of coal benches exposed to air, which comprises of front, top and side areas of exposed coal benches represented as a1, a2 and a3 as shown in Figure 9. Additional area is the area within the two affected pillars towards dip from the active coal face. This comprises of a) area around affected pillars, b) area along strike between affected pillars and c) area between the affected pillars along dip.
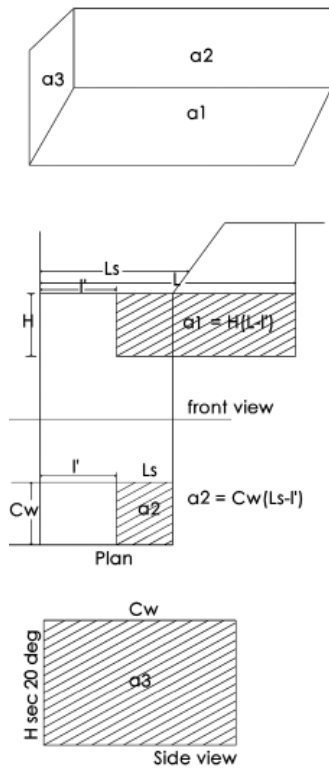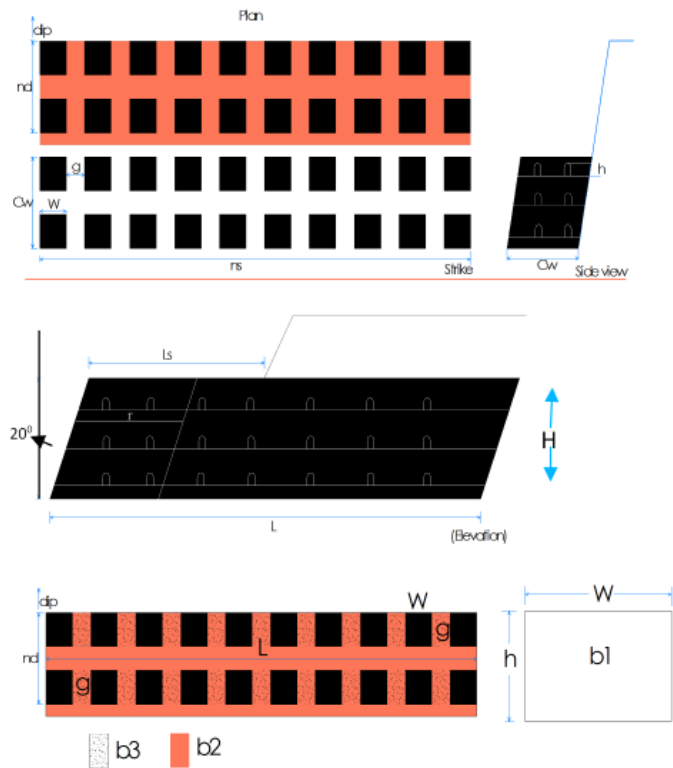
Fig. 9. Area showing a1, a2 and a3; the apparent area

Fig. 9(a). Schematic diagram showing total area exposed to air 'e'& Additional area 'b1, b2, and b3

3.1.1. Apparent area

Apparent area is the area of coal benches exposed to air. It comprises of front, top and side areas of exposed coal benches represented as a1, a2 and a3 as given in Figure 9. These three areas are calculated by the following relations:

a1 = H (L-l'),
a2 = Cw (Ls-l'),
a3 = Cw H sec 20°, where,
a1 = Front area of exposed coal bench, m^2,
a2 = Top area of exposed coal bench, m^2,
a3 = Side area exposed of Coal bench, m^2,
H = Working height of seam under extraction, m,
L = Strike length (High wall exposed), m,
l' = Coal face advance per month, m,
Cw = Cut width, m,
Ls = Coal face length exposed, m.

The aforementioned symbols are also presented in Figure 9 for easy understanding of the relationship derived from geometrical calculations.

3.1.2. Additional area

Additional area is the area within two affected pillars towards dip side from the active coal face. This comprises of the summation of three areas, i.e. b1, b2 and b3. The details of which are as given below;

b1 = area around affected pillars, m^2,
b2 = area along strike between affected pillars, m^2,
b3 = area between the affected pillars along dip, m^2.

The areas represented by b1, b2 and b3 may be calculated by using the following relationship.

b1 = 8WnshN,
b2 = 4LgN,
b3 = 4gWnsN.

where,

W — is coal pillar width, m
ns — is number of Pillars in strike direction
h — is height of the developed gallery, m
N — is number of sections developed
g — is width of the developed gallery, m

Therefore total area exposed (e) may be given by the following relation;

Apparent area + Additional area

$$e = (a1 + a2 + a3) + (b1 + b2 + b3) \tag{1}$$

3.2. Rate of coal face advance

The rate of coal face advance is observed on a monthly basis at the mine site itself vis a vis occurrence of fire or absence of it, at the mine.

As mentioned earlier, the other input parameters governing the occurrence of fire is the rate of coal face advance (m/month) which will be indirectly depending upon the production target of the mine, i.e. million tonnes per year (Mty). It is obvious that higher the production target of the mine, higher is the rate of face advance.

From the aforementioned analysis, the parameters are chosen for field observations and these are presented as independent variables in Table 1.

It may be mentioned here that extensive field observations have been carried out in 13 different opencast mines spreading over the whole country in different coalfields, where coal seams were developed in form of pillars and currently being extracted by opencast method. The field observations have been carried out for three years duration in each of the mine and all independent variables as mentioned in Table 1 have been observed and recorded for detailed analysis.

One such case as a sample i.e. Ghugus Opencast Mine is presented to give an idea about the magnitude of field observations undertaken in this study. The field observations of independent variable of Ghugus Mine for the financial year April 2009-March 2010 are presented

in Table 2(a) and the rate of coal face advance and components of different area as well as the total exposed area for the same financial year are presented in Table 2(b). The occurrence of fire during observation period have also been mentioned in Table 2(b). It may be mentioned here that during subsequent two years April 2010-March 2012, there was increase in production target of the mine and as a result the cut width of opencast mining operation was increased from 40 m to 70 m and all other parameters were not changed.

However, due to increase in cut width, the rate of progress of coal bench and area of coal exposed to air were changing. During this period, a number of fires were observed and the detailed observations on the rate of face advance, area of coal exposure and observation of fire are presented in Table 3.

TABLE 1

Variables Critical to Fire

Sl. No.	Parameters Critical to fire (CTF)	Independent Variables governing the parameters critical to fire		Symbols used for independent variable
i	Total area of coal exposed to air "e"	I.	Strike length(High wall exposed), m	L
		II.	Coal face length exposed, m	Ls
		III.	Working height of seam under extraction, m	H
		IV.	Coal pillar width, m	W
		V.	Height of the developed gallery, m	h
		VI.	Width of the developed gallery, m	g
		VII.	Cut width, m	Cw
		VIII.	Coal face advance per month, m	l'
		IX.	Number of Pillars in strike direction	ns
		X.	Number of pillars in dip	nd
ii	Rate of coal face advance in m/month	XI.	Production target of the mine in million tonnes per year	Mty

4. Field observations at Ghugus opencast mine

The sample data of Ghugus Opencast Mine is presented in this section in Table 2(a) and Table 2(b) for the year 2009-10 and in Table 3 for 2010-12.

It may be observed from aforementioned tables that there has been an increase in Critical width (Cw) during 2009-10 and 2010-12.

TABLE 2(A)

Operating parameters of Ghugus Opencast Mine for 2009-10

No of Sections	N	3
No of Pillars in strike	Ns	48
Pillar Width	W	25 m
Cut width	Cw	40 m
Gallery Width	g	4 m
Strike Length	L	1200 m
Gallery height	h	3 m

Working height	**H**	20 m
Strike exposed length	**Ls**	270 m
No of pillars in dip	**nd**	2
Rate of coal face advance (m/month)	**l'**	

TABLE 2(B)

Calculated parameters on the basis of rate of face advance for Ghugus Opencast Mine for 2009-10

Month	l' (m)	a1 (m^2)	a2 (m^2)	a3 (m^2)	b1 (m^2)	b2 (m^2)	b3 (m^2)	e (m^2)	Remarks
April	100	22000	6800	851.2	86400	57600	57600	231251.2	
May	110	21800	6400	851.2	86400	57600	57600	230651.2	
June	100	22000	6800	851.2	86400	57600	57600	231251.2	
July	80	22400	7600	851.2	86400	57600	57600	232451.2	Fire
Aug	90	22200	7200	851.2	86400	57600	57600	231851.2	
Sept	90	22200	7200	851.2	86400	57600	57600	231851.2	
October	80	22400	7600	851.2	86400	57600	57600	232451.2	Fire
Nov	95	22100	7000	851.2	86400	57600	57600	231551.2	
Dec	100	22000	6800	851.2	86400	57600	57600	231251.2	
January	110	21800	6400	851.2	86400	57600	57600	230651.2	
Feb	100	22000	6800	851.2	86400	57600	57600	231251.2	
March	120	21600	6000	851.2	86400	57600	57600	230051.2	

TABLE 3

Calculated parameters on the basis of rate of face advance for Ghugus Opencast Mine for 2010-12

Month	l' (m)	a1 (m^2)	a2 (m^2)	a3 (m^2)	b1 (m^2)	b2 (m^2)	b3 (m^2)	e (m^2)	Remarks
1	2	3	4	5	6	7	8	9	10
April	89	22220	12670	1489.6	86400	57600	57600	237979.6	
May	89	22220	12670	1489.6	86400	57600	57600	237979.6	
June	89	22220	12670	1489.6	86400	57600	57600	237979.6	
July	72	22560	13860	1489.6	86400	57600	57600	239509.6	Fire
Aug	70	22600	14000	1489.6	86400	57600	57600	239689.6	Fire
Sept	70	22600	14000	1489.6	86400	57600	57600	239689.6	Fire
October	81	22380	13230	1489.6	86400	57600	57600	238699.6	
Nov	80	22400	13300	1489.6	86400	57600	57600	238789.6	Fire
Dec	81	22380	13230	1489.6	86400	57600	57600	238699.6	
January	100	22000	11900	1489.6	86400	57600	57600	236989.6	
Feb	95	22100	12250	1489.6	86400	57600	57600	237439.6	
March	100	22000	11900	1489.6	86400	57600	57600	236989.6	
April	80	22400	13300	1489.6	86400	57600	57600	238789.6	
May	88	22240	12740	1489.6	86400	57600	57600	238069.6	
June	100	22000	11900	1489.6	86400	57600	57600	236989.6	
July	70	22600	14000	1489.6	86400	57600	57600	239689.6	Fire
Aug	70	22600	14000	1489.6	86400	57600	57600	239689.6	Fire
Sept	75	22500	13650	1489.6	86400	57600	57600	239239.6	Fire
October	90	22200	12600	1489.6	86400	57600	57600	237889.6	

1	2	3	4	5	6	7	8	9	10
Nov	100	22000	11900	1489.6	86400	57600	57600	236989.6	
Dec	110	21800	11200	1489.6	86400	57600	57600	236089.6	
January	120	21600	10500	1489.6	86400	57600	57600	235189.6	
Feb	0.5	23990	18865	1489.6	86400	57600	57600	245944.6	Fire
March	0.5	23990	18865	1489.6	86400	57600	57600	245944.6	Fire

5. Statistical analyses of data

Statistical analyses have been carried out to find out the parameters which could be controlled and the actions to be taken for reducing the occurrence of fire. Since, the data for rate of face advance and total area of coal exposure have been found to be highly correlated; therefore, it would be sufficient to carry out statistical analysis (ANOVA) only for the rate of face advance (l'), which is presented in the following sections.

5.1. Interval Estimation

Interval estimation is a reliable and popular statistical tool to provide the most probable intervals of important parameters. The method is to choose for some small value of a (5% or 1%) and then to determine the constants say C_1 and C_2 such that

$$P(C_1 < q < C_2) = 1 - \alpha \tag{2}$$

where q is the parameter of interest. The quantities C_1 and C_2 are known as the confidence limits, the interval $[C_1, C_2]$ is known as confidence interval and $1 - \alpha$ is called the confidence coefficient.

5.1.1. Confidence Interval (95%) for Rate of Coal Face Advance (l') and total area f coal exposure 'e'

5.1.1.1. Case of no-Fire occurrence

To find out the most probable range of Rate of Coal face advance (l') in case of no Fire for Ghugus Opencast Mine working over developed coal pillars, three years data (2009-12) on monthly basis have been collected and it was noticed that in 15 observations, no Fire was observed. The criterion of no fire was set up as, in any particular month if there is no occurrence of fire, all through the three years of observations. Based on this criterion, 15 observations of no Fire were observed. Therefore, looking on the sample size, it has been decided to use the t-statistic for the purpose of determining 95% Confidence Interval [C.I.] of l'. The mathematical structure of 95% C.I. of l' is given as $[\pm t_{0.025}^{n-1} \sigma \sqrt{n}]$, where $\bar{x}$ is sample mean of the data, σ is the standard deviation, 'n' is the sample size and $t_{0.025}^{n-1}$ is the tabulated value of t statistic. Based on the above formulae, the 95% confidence interval of l' for Ghugus Opencast Mine is calculated as [72.20, 94.48] m/month. This range indicates that there is a high probability (0.95) that the fire will not take place if l' is maintained in the above interval or more with respect to the present dimensions and operational limits of the mine. Similarly, the 95% confidence interval for total surface area of coal exposure 'e' for Ghugus Opencast Mine is calculated as [233561.41, 237078.59] m^2 during the

month. This range indicates that there is a high probability (0.95) that the fire will not take place if 'e' is observed in the above interval or less by maneuvering the parameters governing its area as given in equation (1) with respect to the present dimensions and operational limits of the mine.

5.1.1.2. Case of Fire occurrence

To find out the most probable range of Rate of Coal face advance (l') in case of fire occurrence for Ghugus Opencast Mine working over developed coal pillars, three years data (2009-12) on monthly basis have been collected and sorted. The criterion of fire occurrence was set up like as in any particular month, all through the three years of observations, if there is any occurrence of fire. There were 21 observations in which fire were observed. Proceeding on the similar way, the 95% C.I. of l' for the case of fire occurrence in Ghugus Opencast Mine is calculated as [52.44, 76.89] m/month. The range indicates that there is a high probability (0.95) that the fire will take place if l' falls in the above interval with respect to the present dimensions and operational limits of the mine. However, if the rate of face advance is less than the lower limit indicated above, the fire will certainly occur. Similarly, the 95% confidence interval for total surface area of coal exposure 'e' for Ghugus Opencast Mine is calculated as [234962, 239100] m^2 during the month. This range indicates that there is a high probability (0.95) that the fire will take place if 'e' falls in the above interval or more with respect to the present dimensions and operational limits of the mine.

5.2. Analysis of variance

The analysis of variance (ANOVA) is a powerful statistical tool for tests of significance. By this technique, the total variation in the sample data is expressed as the sum of its non-negative components where each of these components is a measure of the variation due to some specific independent source or factor. The ANOVA consists the estimation of amount of variation due to each of the independent factors/causes separately and then comparing these estimates due to assignable factors with that of chance factor. Levin and Rubin (1998)

5.2.1. Analysis of Variance of no-Fire Occurrence

In this section, ANOVA-Two-way classification with one observation per cell is presented. For classification purposes, two assignable causes, viz. Years and Months, have been identified. For preparing the layout of ANOVA-Two-way classification, the data for no fire case has been collected and presented in Table 4.

TABLE 4

Layout of ANOVA-Two-Way classification for Ghugus mine (no-Fire)

Months	Rate of progress of coal face(m/month) during the years		
	2009-10 (y_1)	2010-11 (y_2)	2011-12 (y_3)
January	63.3	100.5	120.5
April	57.5	89.5	80.5
May	63.3	89.5	88.5
June	57.5	89.5	100.5
Dec	57.5	81.5	110.5

Based on the above data, the following two hypotheses are tested:
(i) Whether "Years" are differing significantly?
   H_0y: $y_1 = y_2 = y_3$
   H_1y: $y_1 \neq y_2 \neq y_3$
(ii) Whether "Months" are differing significantly?
   H_0m: $m_1 = m_2 = m_3 = m_4 = m_5$
   H_1m: $m_1 \neq m_2 \neq m_{3 \neq} m_4 \neq m_5$

To test the above hypotheses, the following ANOVA table has been obtained and presented in Table 4(a).

TABLE 4(A)

ANOVA of no-Fire occurrence data

Sources of variation	Degree of freedom	Sum of squares	Mean sum of squares	Variance ratio (F Value)	Tabulated F Value
year	2	4398.6	2199.48	25.93*	$F_{.05}^{(2,8)} = 4.46$
month	4	588.34	147.1	1.73	$F_{.05}^{(4,8)} = 3.84$
error	8	678.76	84.8		
total	14	5665.7			

* Result is highly significant

From the aforementioned ANOVA table, it is concluded that 'Years' are significant while 'Months' are not significant. The detailed explanation on significance of 'Years' and 'Months' are mentioned in the following section.

5.2.1.1. Critical Difference (CD)

Since, the 'Years' are significant, therefore, in this section it is desired to identify the pair of 'Years' which are differing significantly. For this purpose, the critical difference (CD) of each pair of Years is calculated. The formula used for critical difference is as follows:
The pair of years' y_i and y_j are significant, iff, the following condition is satisfied.

$$\left| \bar{y}_i - \bar{y}_j \right| \geq t_{0.025} (r-1)(s-1) s_e \sqrt{\frac{1}{n_i} + \frac{1}{n_j}} \qquad (3)$$

where $\bar{y}_i$ and $\bar{y}_j$ are the means of ith and j^{th} year and s_e is the square root of mean sum of square due to error, n_i and n_j are the number of observations in the ith and j^{th} years and $t_{0.025} (r-1)(s-1)$ is the t value as 2.306. 'r' is the number of years and 's' is the number of months.

Therefore,
(i) For the (Year 1, Year 2) and (Year 1, Year 3), the respective values of CD are 40.28 and 30.28 respectively which are greater than 13.42 (i.e. the value of the R.H.S of equation (3).These results indicate that (Year 1 and Year 2) and (Year 1 and Year 3) are differing significantly in terms of rate of coal face advance.

(ii) For the (Year 2 and Year 3) the CD is 10, which is less than 13.42 (i.e. the value of the R.H.S of equation (3). This result indicates that the year 2 and year 3 are almost of similar nature in terms of rate of coal face advance.

From the aforementioned results, it may be seen that for the year 2009-10, the rate of coal face advance is significantly differing from the years 2010-11 and 2011-12 and its average rate of coal face advance is also beyond the 95% confidence interval calculated for l'. This indicates that some other factors (mining parameters) may be responsible for the occurrence of no fire in the year 2009-10. One of the reasons may be the less cut width of 40 m and regular advance of coal face all through the year, where as in following two years the cut width has been increased to 70 m but the rate of coal face advance was not maintained uniform and regular. The stoppage or slowness of face that had happened at the mine has been manifested as fire. The fiery situation may have been further supplemented by increase in apparent area due to increase in cut width.

5.2.2. Analysis of Variance of Fire Occurrence

In this section, ANOVA-Two way classification with one observation per cell is presented. For classification purpose, two assignable causes, viz. 'Years' and 'Months', have been identified. For preparing the layout of ANOVA-Two-way classifications, the data for Fire cases have been collected and presented in Table 5. The layout of 'fire' data table will comprise of those entries in which in any particular month, all through the three years of observations, if there is any occurrence of fire.

TABLE 5

Layout of ANOVA-Two-Way classification for Ghugus mine (Fire)

Months	Rate of progress of coal face (m/month) during the years		
	2009-10 (y_1)	2010-11 (y_2)	2011-12 (y_3)
July	46.2	72.5	70.5
August	52.0	70.5	70.5
Sep	52.0	70.5	75.5
Oct	46.2	81.5	90.5
Nov	55.3	80.5	100.5
Feb	57.5	95.5	0.5
March	69.0	100.5	0.5

Based on the above data, similarly the following hypotheses are again tested:

(i) Whether "Years" are differing significantly?

H_0y: $y_1 = y_2 = y_3$

H_1y: $y_1 \neq y_2 \neq y_3$

(ii) Whether "Months" are differing significantly?

H_0m: $m_1 = m_2 = m_3 = m_4 = m_5 = m_6 = m_7$

H_1m: $m_1 \neq m_2 \neq m_{3 \neq} m_4 \neq m_5 \neq m_{6 \neq} m_7$

TABLE 5(A)

ANOVA of fire occurrence

Sources of variation	Degree of freedom	Sum of squares	Mean sum of squares	Variance ratio F	Tabulated F Value
Year	2	3088.19	1544.09	1.89 (N.S.)	$F_{.05}^{(2,12)} = 3.89$
Month	6	1543.74	257.21	0.315(N.S.)	$F_{.05}^{(6,12)} = 3.00$
Error	12	9798.57	816.54		
Total	20	14430.5			

N.S. = Non-Significant

From the aforementioned ANOVA Table 5(a), it may be observed that 'Years and Months' are not significant. This implies that variation in rate of coal face advance is least affected by both these factors (Years and Months) for the occurrence of fire.

6. Conclusions

The observations over a period of three years (2009-12) have been subjected to statistical analyses and there emerges features of occurrence of fire vis-a-vis rate of coal face advance in opencast mines working over developed pillars. The confidence interval approach has suggested a range of rate of coal face advance (l') for no fire occurrence at Ghugus mine with its current dimensions and operating parameters as [72.20 to 94.98] m/month with 0.95 probability while for occurrence of fire, the range of (l') is coming as [52.44 to 76.89] m/month at $t = 2.086$ at degree of freedom 20. Similarly, the 95% confidence interval for total surface area of coal exposure' e' for Ghugus Opencast Mine is calculated as [233561.41, 237078.59] m^2 during the month for no Fire occurrence and [234962, 239100] m^2 for Fire occurrence. It may be noticed from the ANOVA Table 4(a), that 'Years' being highly significant in case of no Fire occurrence, the hypothesis H_0y is rejected and H_1y is accepted while 'Months' being non significant, H_0m is accepted.

Similarly for Fire occurrence as evident from Table 5(a), H_0y and H_0m are accepted. It may be appropriate to mention here that maintaining a regular and uniform rate of coal face advance is far more critical to occurrence of fire than having a larger bench dimensions or a higher magnitude of rate of coal face advance i.e., (l') but on an intermittent pattern. This is evident from the statistical inferences derived and its analyses make it rather more obvious. The significant variations of rate of coal face advance between Years and Months have also been tested and suitable interpretation are presented which may be helpful to the mining industry for prevention/handling of fire in opencast mines working over developed coal pillars. Therefore what emerges for decision making is that even though the interval of (l') for no fire occurrence in the mine Ghugus is [72.20 to 94.98] m/month, there lies a small range of overlap with (l') of the fire occurrence [52.44 to 76.89] m/month as [72.20 to 76.89] m/month. Similar analysis has been done for total area of coal exposure 'e' as indicated above. This suggests that for safety reasons and to prevent any chance of outbreak of fire at coal face, the rate of coal face advance has always to be ensured higher than 76.89 m/month and total area of coal exposure 'e', lower than 233561.41 m^2 in case of Ghugus mine in the present operational dimensions of quarry. Based on these findings, it may

be suggested that smaller bench dimensions and faster rate of regular face advance are critical to be observed throughout the mining operation while extracting coal pillars by opencast method.

The limitation of this study done and the findings thereof is the small size of sample data. The scope for further study with higher sample size would render finer insights into the problem of occurrence of fire in opencast workings over developed coal pillars.

References

Levin I.R., Rubin S.D., 1998. *Statistics for Management*. Chi-Square and Analysis of Variance, pp. 567-644, Pearson Education, Delhi, India.

Panigrahi D.C., 1996. *A Study of Fire Problem in an Opencast Mine over Developed Pillars and its Abatement Measures*. MIF-1996, Calcutta, India, pp. 319-330.

Singh T.N., 2013. *Surface Mining of Coal seams Standing in Pillars*. Surface Mining, pp. 183-195, Lovely Prakashan, Dhanbad, India.

Vijh K.C., 1995. *Productivity improvement due to proper technology applications in opencast mines-case studies*. National seminar on People Technology and Productivity, Nagpur, India, pp. 29-33.