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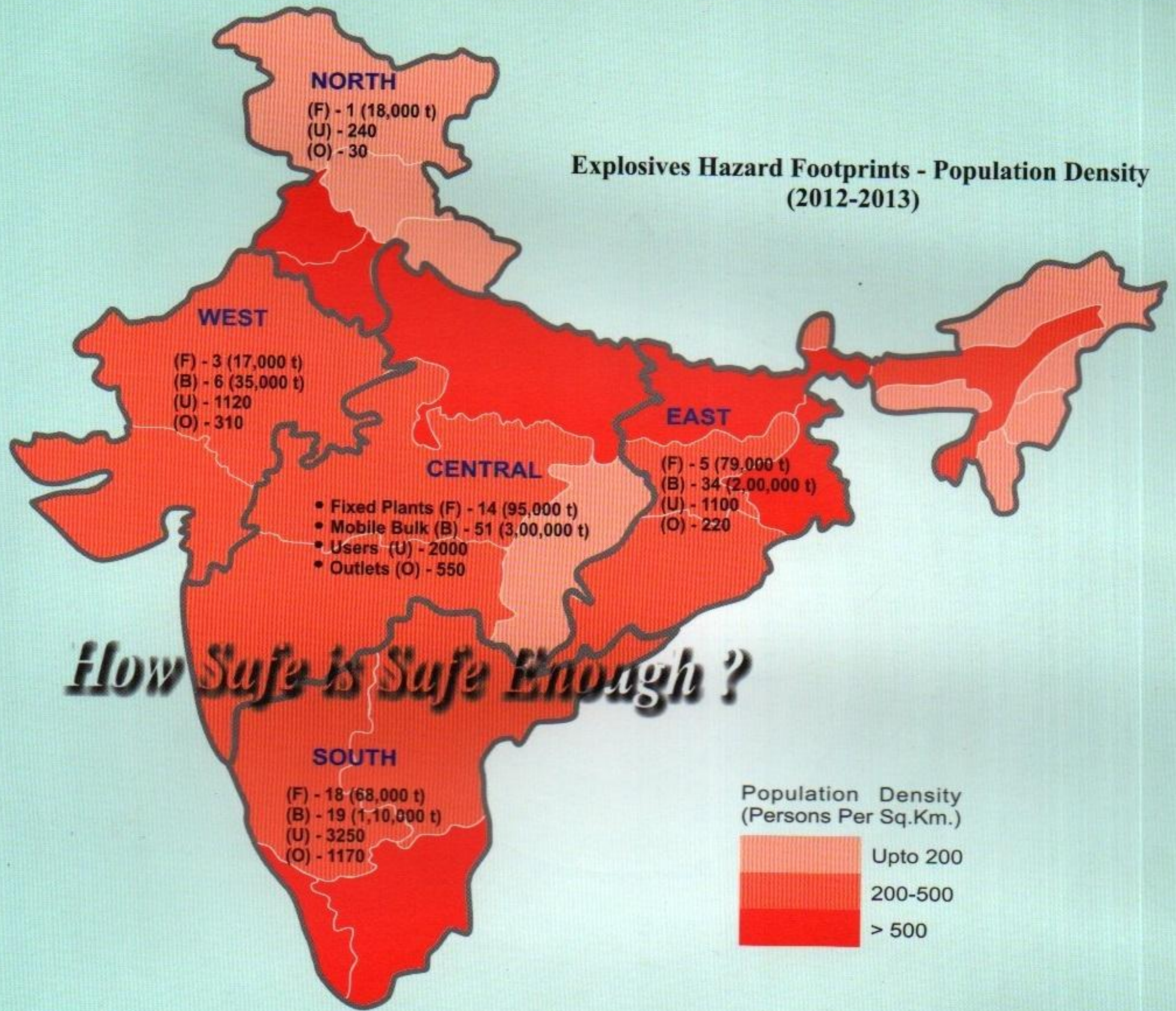
JOURNAL OF THE EXPLOSIVES SAFETY AND TECHNOLOGY SOCIETY (VISFOTAK) INDIA, DEALING WITH SAFETY AND TECHNOLOGICAL ASPECTS OF THE EXPLOSIVES INDUSTRY



The 'explosives market – population density' matrix of populous India, shown above, illustrates the challenges in risk management of commercial explosives operations, poised to further aggravate with rapid industrialization and urbanization of the country. To be forewarned is to be forearmed !

Cover Feature : Quantitative Risk Assessment (QRA)

(Risk – Based probabilistic approach for safety assessment in commercial explosives operations and it's relevance for the explosives industry in India)

MISSION STATEMENT

"To proactively establish a sustainable interface between all major constituents of the Explosives Industry : The Users, the Regulatory Bodies, the Manufacturers, the Academic and Research Institutions, et.al., in order to foster and promote modern concepts and practices, relating to Safety and Technology of Explosives."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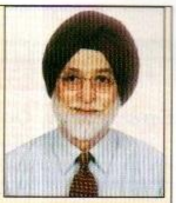
Editorial...



"We are what we repeatedly do. Excellence then is not an act but a habit - Aristotle"

The growth of the explosives industry as a key resource for economic development, world wide, is a fascinating narrative of an inexorable tradeoff between 'economic' benefits and 'tolerability' of risks associated with the industry. There was a time when NG was deemed to be the safest explosive, only to be phased out later with the emergence of much safer and more efficient explosives blasting systems

To quote David Kane 1992, "There are three basic disparities that exist in the way risk is dealt with : a) differences in the way risk is perceived; b) differences in the way risk is measured, and c) differences between these perceptions and measurement".

Indeed, it was the disparity between the public perception and the measurement of risk, that motivated WASH-1400, a 'Probabilistic Safety Assessment (PSA) Report', commissioned by the US Nuclear Regulatory Commission in 1975, that quantified the risks associated with the operation of all electricity generating nuclear power plants in the US, to demonstrate that the actual risk was less than other industrial facilities. This study is considered the 'grandfather' of modern probabilistic risk assessment protocol popularly known as QRA.

Whilst QRA has since gained traction with almost all the major industrial explosives producing countries, there's been unfortunately no comparable movement in India even though, paradoxical as it may appear, the explosives industry was introduced to QRA as far back as 1983 during the 'National Seminar on Safety in Industrial Explosives' organized then by the Department of Explosives at Nagpur. A paper on probabilistic risk assessment techniques was presented at the seminar by Dyno Industries, Norway, perhaps the first commercial explosives company to apply this technique in response to the growing concern for safety in an increasingly urbanized socio-economic environment of rapid industrialization which required compliance with the prescribed individual fatality criteria as mandated. Significantly, the new emerging risk assessment protocol duly lent strong impetus for development of automated / remotely controlled continuous manufacturing processes in the explosives industry.

India is densely populated with an average population density of 400 persons per sq.km. To put it in perspective vis-à-vis the explosives industry, close to 1000t of high explosives (not including explosives produced by mobile 'on-site bulk mixing and delivery' units that constitutes over 70% of the market), 3 million detonators, 1 million meters of detonating fuses, are delivered daily from 41 fixed plants through a complex net work of over 2000 outlets, servicing close to 8000 licensed users. A moving van load of 10t of explosives would envelop more than 200 persons within its potential damage zone at any point in time .

In such a milieu, therefore, QRA protocol for safety in explosives operations in India deserves serious consideration; and that is the burden of the 'cover feature' in this edition : How Safe is Safe enough ?

I wish to record my deep appreciation of the support received from the Institute of Makers of Explosives (IME), USA, by contributing two excellent papers on the efficacy of QRA, in commercial explosives operations based on IME's proprietary software IMESAFR developed specifically for the explosives industry.

Before concluding, I would like to share my profound sense of sorrow and loss with the passing away of Shri Rangachari Raghavan, on May 1, 2015, after a prolonged illness.

A founder member of Visfotak, Ranga, as he was fondly called by his colleagues, was our mentor and guide every step of the way in launching this Journal in 2006, and actively promoting it in later years. We shall sorely miss him, and extend our heartfelt condolences to his gracious wife and other members of his family. R.I.P - Ranga !

Ardaman Singh

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- Accepted as 'Liaison Member' by the Institute of Makers of Explosives (IME), USA.

Sri Rangachari Raghavan (1935-2015)

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COVER FEATURE & SUPPLEMENT

COVER FEATURE

Quantitative Risk Assessment (QRA)

(Risk - Based probabilistic approach for safety assessment in commercial explosives operations and it's relevance for the explosives industry in India)

1.0 Prologue :

1.1 The earliest recorded reference to the application of QRA in commercial explosives industry, perhaps for the first time in India, came about at the National Seminar on 'Safety in Industrial Explosives' held in 1983 at Nagpur, under the aegis of the Office of the Chief Controller of Explosives, Department of Explosives, where a technical paper titled 'Aspect of Planning of an Explosives Plant with Consideration to Internal and External Safety Distances', was presented by Mr. Krogsite on behalf of Dyno Industries A-S, Explosives Division, Norway.

1.2 Dyno had developed a risk-based 'Probabilistic' analytical technique for assessment of safety, perhaps the first such application by a commercial explosives company globally, responding to the unique situation of rapid urbanization in Norway (and generally so in Europe) during the 1970s/1980s; consequently, having to establish or manage explosives manufacturing facilities closer to inhabited areas. Threshold acceptance criteria of individual fatality rate P(f), shown below, were prescribed, heralding a paradigm shift in the protocol for risk assessment in commercial explosives operations.

- Internal surroundings (plant buildings, terrain profile, persons exposed and frequency of exposure) :

  P(f) - 5.0×10^{-8} per yr. (Norway's Industrial Standard)

- External surroundings (around the plant, and around storage magazines beyond the plant premises) :

  P(f) - 0.1×10^{-8} per yr. (Lower than the risk from fire in Norway)

The technical paper referred to above, has been reproduced for its historical significance, as a 'Supplement' to this 'cover feature'.

1.3 To wit, considerable water has flown down the Ganges since 1983 !.

With the advances in computational techniques, and the development of 'Algorithmic Information Theory', during the second half of last century, new dimensions to 'probability theory' have been added. A brief perspective is presented in Box - 1 / Box - 2 / Box - 3, respectively.

Quantitative Risk Assessment (QRA)

Box - 1

- 'Risk' is defined as *"The likelihood that a specified undesired event will occur due to the realization of a hazard by / or during work activities, or by the product and services created by work activities"*.
- Generally four systemic phases are distinguished in literature on risk assessment, as follows:-
  - ◆ *Qualitative analysis* : Definition of the system and the scope, identification and description of the hazards, failure modes and scenarios.
  - ◆ *Quantitative analysis* : Determination of the probabilities and consequences of the defined events. Quantification of the risk in a risk number or a graph as a function of probabilities and consequences.
  - ◆ *Risk evaluation* : Evaluation of the risk on grounds of the results of the former analyses. In this phase the decision is made whether or not the risk is tolerable.
  - ◆ *Risk control and risk reduction measures* : Depending on the outcome of the risk evaluation, measures may have to be taken to reduce the risk. It should also be determined how the risks can be controlled (for example by inspection, maintenance or warning systems).
- The decision-making regarding risks is a complex process; that not only technical aspects but also political, psychological and social processes play an important role. A schematic illustration of the process of risk analysis is provided below as an example.

Risk Analysis

1st question:
What can go wrong?
Qualitative (deterministic) response.

2nd question :
How "likely" is it that this will happen?
Qualitative (deterministic) or quantitative (probabilistic) response.

3rd question :
If it does, what are the consequences?
Qualitative (deterministic) or quantitative (deterministic or probabilistic) response.

4th question:
Is the risk acceptable ?
Acceptance individual risk criteria for various risk activities, respectively.

- The illustration highlights two approaches :
  - i) 'Deterministic Approach' (see Box-2) where systemic variables have known values and connected by predictable behavior;
  - ii) 'Probabilistic Approach' (see Box-3) where systemic behavioral uncertainties exist, and may require induction of 'randomness' into the system to describe the systemic components and their interactions.

However, a caveat is in order here, that induction of 'randomness' in any operating system must extensively draw upon organizational experience and a reliable database created for the purpose duly corroborated by relevant tests as needed. Therefore, it will be true to say that in real world, 'Randomness' and 'Determinism' are not mutually exclusive, and indeed, the two approaches are often applied in tandem to expand the range of risk judgment values for rational decision making and devising appropriate control measures.

(The "Cover Feature" is an 'In-House' contribution, as part of the running serial on "Challenges and Issues" of the Explosives Industry - Editor)

1.4 It is also interesting to note that the development of QRA for explosives, was first initiated by the Defense Establishments in the NATO countries in Europe, beginning the 1970s, for safe selection of sites for storage of military explosives, which later gained traction beyond Europe. See Figure 1.

1.5 For example, the Department of Defence Explosives Safety Board (DDESB), USA, taking cue from the developments in Europe, chartered a working group RBESCT (Risk Based Explosive Safety Criteria Team), in 1997, to study the feasibility of using risk based analytical models for explosives safety. The RBESCT in collaboration with APT Research, Inc., duly developed a software SAFER (Safety Assessment for Explosives Risk) - for determination of safety criteria for military ammunition and explosives storage site.

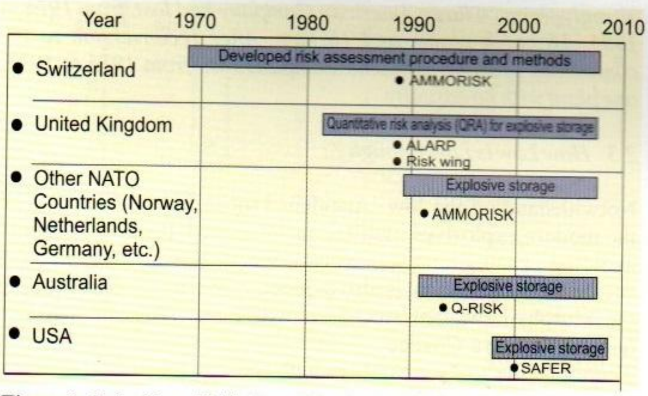


Figure 1 - Prior Use of Risk-Based Explosives Safety Criteria (QRA) by the Defense Establishments. (Young et al, 2007)

1.6 And in due course of time, taking cognizance of these developments at DDESB, the Institute of Makers of Explosives (IME) decided in 2005 to fund development of similar tool using SAFER platform, tailored for the commercial explosives industry in North America, and duly developed its proprietary software IME SAFER applicable for commercial explosives operations, intended to supplement or provide an alternative to the American Table of Distances (ATD) / Table of Separation Distance (TSD), and fill the gaps where standards don't exist.

1.7 Where as, the explosives industry in India, despite the early introduction to QRA in 1983, has apparently remained oblivious of the aforesaid developments. However, in the interregnum period, the industry has come a long way with an impressive growth trajectory since and currently ranked amongst the major producers of commercial explosives. Alongside this growth, the regulatory dispensation has also commensurately evolved, undergoing revisions over time and currently being administered by the latest revised Explosives Rules 2008.

It's therefore an opportune moment, ***rather be late than never!***, to take cognizance of the emerging probabilistic approach to risk analysis and develop a perspective on the relevance of QRA for the explosives industry in India, which is attempted in this 'cover feature'.

Deterministic Approach

Box - 2

- **Hazard Operatability (HazOp)**

i) Identify and list every likely risk.
ii) Determine likely frequency of every risk occurring and assign it a rating, say, on a scale of 1 to 10 (1 being extremely unlikely and 10 extremely likely).
iii) Similarly, estimate the likely consequences of every risk event, and assign a rating on a scale of 1 to 10.

- **Risk Matrix**

i) Map out the severity ratings, i.e. "frequency x consequences", into the appropriate cells of a risk matrix format as below:-

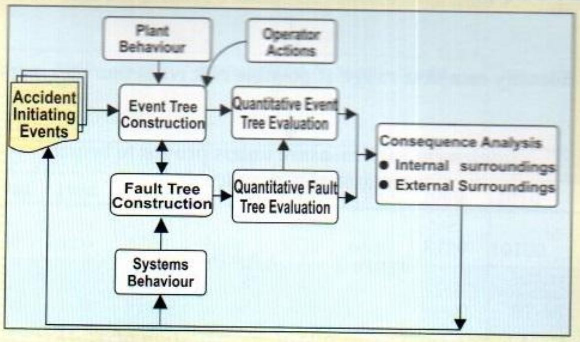
Rating → / Frequency ↓		Consequence 1 Insignificant	2 Minor	3 Moderate	4 Major
1	Unlikely	Low	Low	Moderate	High
2	Moderate/ Possible	Low	Moderate	High	Very High
3	Likely	Moderate	High	High	Very High
4	Almost Certain	Moderate	High	Very High	Extreme

ii) Prioritize risks according to the severity (frequency x consequence) and develop appropriate control measures for implementation.

Probabilistic Approach

Box - 3

- **Sequence of Analysis Steps**



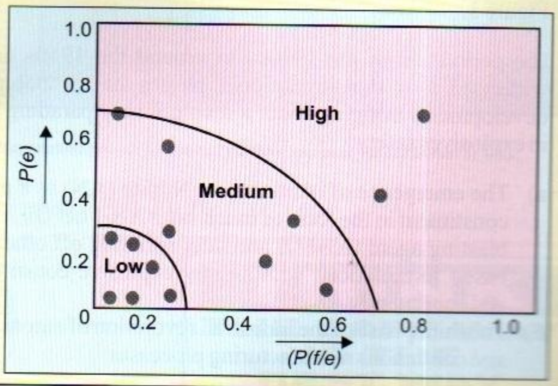
- **Consequence Analysis**

The numerical estimates of frequency and consequences for different risk events are duly translated into probability of individual fatality [P(f)] as a function of three components as per the following equation, in order to assess whether the risk is low enough to proceed vis-a-vis the acceptable individual risk criteria.

$P(f) = P(e) \times P(f/e \times E(p)$

where,

P(e) - *probability of an event occurring;*
P(f/e) - *probability of fatality given an event;*
E(p) - *the expected exposure of people.*



2. Discussions :

2.1 Explosives ≡ Hazard ≡ Risk (Likelihood x consequence) ≡ Acceptance criteria of individual risk :

Given the historical TINA (There Is No Alternative!) factor associated with the commercial explosives industry as a key resource for economic development, and concomitantly, the paramount importance of 'Safety' of persons exposed to explosives operations, the industry has had a long history of legislative oversight, in order to control and reduce risk to levels 'as low as reasonably practicable (ALARP)', such that the industry is sustainable to deliver 'Economic Value with Safety'. See Figure 2.

Identify & Assess hazard

↓

Confirm minimum acceptance criteria are met

↓

Identify complete range of possible risk reduction measures

↓

Implement each measure unless proven to be not reasonably practicable

Figure 2 - ALARP Process

2.2 A historical perspective of the evolution of ALARP Process in the explosives industry :

i) The ALARP Process is initiated by first developing a 'Risk - Tolerability Framework' of an operation, viz -

a) Identification of risks which are not tolerable and entirely avoided; and

b) Risks identified as controllable to acceptable levels and therefore tolerable.

ii) The ALARP process has duly evolved with experience, innovation and performance over time, illustrated in Figure 3.

The period from the 1930s to around the 1950s or so, witnessed two transformational phases of technological developments bringing about a revolutionary parading shift in explosives safety:

a) The emergence of Ammonium Nitrate (AN) as a major constituent in the form of much safer AN-Fuel Oil mixed blasting agent (ANFO) and later spinning off other AN based formulations without any explosive constituent, and congruently -

b) The third phase of the industrial revolution of automation and continuous manufacturing processes.

The two developments together provided unprecedented levels of safety of persons exposed to explosives operations.

Paraphrasing 'Dr. G.S. Biasutti' words drawn from his treatise on 'History of Accidents with Industrial Explosives' : *The period was characterized, in all branches of technology, by the development of automation with the principal objective being to reduce labor cost as well increase safety. Batch manufacturing processes were largely replaced with continuous ones that not only allowed to reduce the number of personnel but to also cut down on the amount of explosive present in the installation. Further, a continuous process was more suited for remote control and automation. As an example, in the manufacture of nitroglycerine, a large American Company had lost, from 1915 to 1955, 16 batch plants and 16 men. After reconversion to the continuous process, the same Company lost, from 1955 to 1975, one plant with no casualty.*

2.3 How Low is Low Enough ? :

Notwithstanding the low 'Accident Probability Index (API)' of the modern explosives industry, as illustrated, the conundrum of avoiding or mitigating serious consequences from an explosives accident endures; and it is also evident, contextually paraphrasing the 'Murphy Law', that 'Accidents' with explosives would always happen if given a 'Chance'.
Therefore, the 'low probability - high consequence' risk paradigm if anything, would indeed, enjoin a more searching and robust analytical techniques.

A historical perspective in this regard is briefly discussed below:-

2.3.1 Q-D Criteria :

Accident with explosive is caused when a quantity of explosive is somehow detonated and in its wake, the resultant shock impulse / over-pressure caused by the explosion could potentially harm person(s) exposed to the blast wave. For example, an over-pressure of 14.5 psi, is deemed close enough to fatality threshold; whereas, an over pressure of 29 psi is close to certainty of fatality (99% probability).

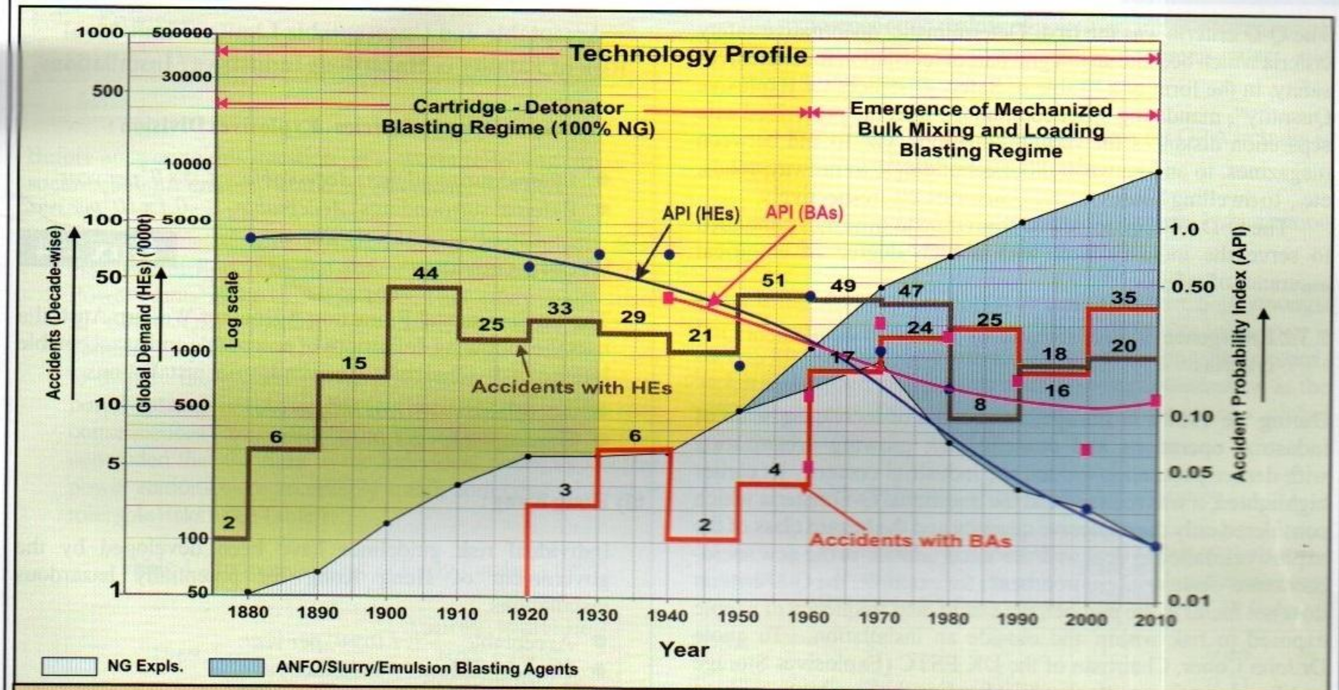
Theoretically, shock pressure impulse is proportional to the cube root of the energy released upon detonation, which attenuates over distance. Thus emerged the criteria of 'Safe Separation Distance' (D) derived for different quantities of explosives, by empirically developing a representative Scaling Law equating the weight of explosive (Q) and safe separation distance (D); shown below as an example :-

$$D = (K)(Q^{1/3})$$

where: D = Safe separation distance or potentially affected distance,

K = Site Constant derived by a series of tests with the explosive material under consideration or its equivalent.

Q = Weight of explosive material under consideration.



Accident Probability Index (API) Profile

Item	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010
1.0 Global Demand											
1.1 High Explosives (HEs) ('000t)	200	290	300	300	520	1100	2600	3600	6680	8720	10100
1.2 Blasting Accessories (BAs)	Reliable data not available										
2.0 Accidents (Decade-wise) (Manufacture and Handling) (Nos.)	**01-10**	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**	**61-70**	**71-80**	**81-90**	**91-00**	**01-10**
2.1 **HEs**											
NG	44	25	31	28	19	47	46	40	-	1	1
AN	-	-	2	1	2	3	2	-	-	-	1
ANFO	-	-	-	-	-	1	1	-	-	-	-
Slurry	-	-	-	-	-	-	-	5	1	3	-
Emulsions Including bulk	-	-	-	-	-	-	-	2	7	14	18
Sub-Total	44	25	33	29	21	51	49	47	8	18	20
2.2 BAs											
Detonators	-	-	3	5	2	3	11	15	18	13	33
PETN	-	-	-	1	-	-	3	3	-	1	1
Det. Fuses	-	-	-	-	-	-	3	4	5	1	1
Cast Boosters	-	-	-	-	-	1	-	2	2	1	-
Sub-Total	-	-	3	6	2	4	17	24	25	16	35
3.0 Accident Probability Index (API)*											
3.1 HEs	-	0.6	0.71	0.70	0.14	0.42	0.22	0.14	0.04	0.03	0.02
3.2 BAs**	-	-	-	0.45	0.14	0.13	0.30	0.25	0.14	0.06	0.11

Note: * $API = \left(\frac{\text{No. of Accidents}}{\text{Period (10 yrs.)}}\right)\left(\frac{1}{\text{Incremental Growth in Demand (Base-1880)}}\right)$ ** The incremental growth in demand for BAs assumed similar to that of HEs.

Figure 3 - History of Accidents with Explosives (1880-2010)

The Q-D criteria was the first 'Deterministic' quantitative safety criteria which became an integral part of legislation for explosives safety, in the form of a "Table of Safety Distances vs. Explosive Quantity", mandating strict compliance with the prescribed safe separation distances for various situations, viz, to and between magazines, to and between process buildings; to railway, roads, etc., to dwelling houses, offices, factories, etc, respectively.

The Q-D criteria, reviewed from time to time, has continued to serve the industry well with a high degree of empirical assurance of safety.

2.3.2 Emergence of 'Probabilistic Approach' to supplement Q-D criteria :

During the 1960's in Europe, on account of increasing scale of industrial operations and consequently, growing urbanization with denser population around the industrial centers, as earlier highlighted, it was realized that the traditional Q-D criteria which considered only the explosive quantity and the hazard class of the explosives, failed to deal with the 'uncertainties' in the new socio-economic - industrial environment ; for example, the Q-D criteria does not factor in the number, the extent and frequency of people exposed to risk within and outside an installation. To quote Dr.John Conor, Chairman of the UK ESTC (Explosives Storage and Transport Committee), whilst funding the feasibility study of risk based quantitative risk assessment (QRA) for explosives storage in 1983 : *"The goals of explosives safety will be unchanged, whereas, the way of achieving those goals will be very different".*

Commensurately, acceptable threshold mortality rates had to be prescribed and mandated for compliance in most countries, as the singular safety determining criteria. (See Box - 4).

2.3.3 Illustrative examples of application of QRA in commercial explosives industry :

i) Dyno Industries (1980s)

As mentioned in the beginning, details of probabilistic / quantitative analytical methodology developed by Dyno, for safety in their commercial explosives operations during the 1980s, is presented as 'Supplement' to this cover feature.

ii) A 'Case-Study' in Greece (2006)

Abstracts from "Quantified Risk Assessment for Plants Producing and Storing Explosives, by Ioannis A. Papazoglou, et al" are presented in Annexure - 1, providing an excellent example of application of QRA in commercial explosives manufacturing facilities.

iii) IMESAFR : 2014

Attention is drawn to the two excellent scientific papers on IMESAFR and its application contributed by IME which have been presented later under 'Scientific and Technical Papers' section of this edition.

Box - 4

Acceptable and Unacceptable Limits of Individual Risk of Fatality in Hazardous Industries / Installations

i) Norway - Dyno Industries , Explosives Division :

- Internal surroundings : *Acceptable* - ≤ 5×0^{-8} *per year*
- External surroundings : *Acceptable* - ≤ - 0.1×10^{-8} *per year*

ii) Western Australia :

The Environmental Protection Agency of Western Australia uses the following definitions of acceptable and unacceptable limits of individual risk for new industrial installations.

- Acceptable - ≤ 1.0×10^{-6} *per year.*
- Unacceptable - ≥ 1.0×10^{-5} *per year.*

iii) Hong Kong :

Individual risk guidelines have been developed by the government of Hong Kong for potentially hazardous installations.

- Acceptable - ≤ 1.0×10^{-5} *per year.*
- Unacceptable - ≥ 1.0×10^{-5} *per year.*

iv) United Kingdom :

The Health and Safety Executive (HSE) is the regulatory authority for hazard identification and risk assessment studies in the United Kingdom.

- Acceptable - ≤ 1.0×10^{-6} *per year.*
- Unacceptable - ≥ 1.0×10^{-5} *per year for small developments;*
  - ≥ 1.0×10^{-6} *per year for large developments.*

v) Netherlands :

The Directorate General for Environmental Protection in the Netherlands published a document entitled *Premises for Risk Management, Dutch Environmental Policy Plan, 1989*. This plan requires companies to quantify the risks associated with industrial activities and then determine their acceptability.

- Acceptable - ≤ 1.0×10^{-8} *per year.*
- Unacceptable - ≥ 1.0×10^{-5} *per year for existing facilities;*
  - ≥ 1.0×10^{-6} *per year for new facilities.*

vi) Petroleos de Venezuela, S.A.

Petróleos de Venezuela, S.A. (PDVSA) published a document entitled *Criterios para el Analisis Cuantitativo de Riesgos* (Criteria for Quantitative Risk Analysis). The document requires companies to evaluate the individual risk levels posed by a project and compare them to the following criteria.

- Acceptable - ≤ 1.0×10^{-6} *per year.*
- Unacceptable - ≥ 1.0×10^{-3} *per year.*

3.0 Epilogue :

3.1 Relevance of QRA for the Commercial Explosives Industry in India :

Before answering this question , it's worth reflecting upon the socio-economic drivers behind the emergence of QRA.

- QRA originated with WASH-1400, a 'Probabilistic Risk Assessment Report on the Safety of Commercial Nuclear Power Plants' in the USA in 1975. This study , a precursor to future QRA models for hazardous industries, was commissioned by the US Nuclear Regulatory Commission, to dispel the general public perception that the nuclear power plants are very risky because the worst case consequences are potentially catastrophic. The report concluded that the risks to the individual posed by nuclear power stations were acceptably small, compared with other tolerable risks. See Table 1.

Table 1 - Individual Risk of Early Fatality (1969)

1969	No. of Accidents	Approx. Individual Risk Fatality Probability / yr.
All accidents in USA	115000	6×10^{-4}
Nuclear accidents (100 reactors)	-	2 x 10-8 (based on population of 15 million at risk)

- Further, quoting David Kane (1992) :

"Risk is a difficult concept to 'measure and effectively use' in decision making".

"There are three basic disparities that exist in the way risk is dealt with -
i) Differences in the way risk is perceived,
ii) Differences in the way risk is measured and
iii) Differences between these perceptions and measurements".

"It calls for science to provide risk assessment along with confidence intervals for their assessments. This puts the value decision of safety into the hands of policy makers. Further, an interface is established to provide policy makers with the tools to make effective risk decisions".

- Finally, though on a philosophical note, it would not be out of place to emphasize, that the disparities in public perception and measurement of risk, in some sense, are also an ubiquitous manifestation of Maslow's 'Theory of Human Motivation' at play in a developed industrialized society, where the governments becoming increasingly engaged in the socio-economic realms of governance, have to recognize the rising human motivation for safe environment and working conditions.

With the above backdrop, the scope for QRA in India is discussed in the following paragraphs :-

3.1.1 Challenges of industrialization and growing Urbanization in an already populous milieu :

India is the second most populous country after China amongst the developing countries. Besides, what further sets India apart is its very high population density, currently averaging 400 persons / sq.km and poised to aggravate with growing urbanization as the country is rapidly industrialized. A comparative global perspective is provided in Table 2.

Table 2 -Industrialization vs. Urbanization

Country	Population Density (persons/sq.km)	Urbanization (% of Population)	Rate of Increase (%)	Relative Industrialization (CIP Index)
USA	35	82	1.3	0.48
China	145	54	2.7	0.33
India	421	31	2.4	0.07
Japan	350	91	0.2	0.54
Germany	230	74	0.1	0.52

3.1.2 'Explosives hazard footprints' and 'Population Density'

Ranked amongst the major explosives producing countries, the geographical dispersal of the explosive market and its sectoral hazard footprints in India, against a backdrop of the population density map is illustrated in Figure 4, and the supporting data is also tabulated below the map (Table 3).

3.1.3 'Forewarned' is 'Forearmed' ! :

India is fortunate in having a long legislative history for regulating safety in commercial explosives operations, beginning with the enactment of Indian Explosives Act in 1875; and soon thereafter, the administration of the Act was centralized by establishing a Departments of Explosives in 1898. The department has since played a stellar role in nurturing and systematically modernizing the explosives industry in the country.

The safety provision in the recently revised Explosives Rules-2008, has brought in significant structural changes, consistent with best global practices, briefly highlighted below, which augurs well for adaptation of QRA. The important new provisions in this regards are :-

a) Adoption of UN Model Regulations concerning Explosives Classification and Categorization including the prescribed 'Manual of Explosives Testing' in this regard;

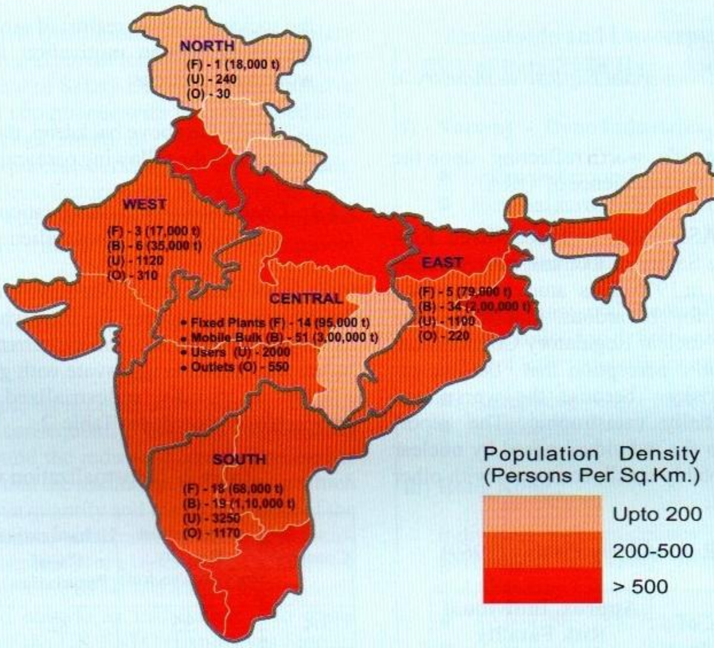


Figure 4 - Explosives Hazard Footprints - Population Density (2012-2013)

Table 3 - Explosives Industry Profile

Items	North	South	East	West	Central	Total
A) Explosives Delivery Regime (2012-13)						
1.0 No. of Production Units:						
1.1 Fixed Plants	1	18	5	3	14	41
1.2 On-Site Mobile Bulk Units	-	19	34	6	51	110
2.0 Demand (Est.):						
2.1 High Explosives (HEs) (Packaged)						
a) Fixed Plants (t)	18,000	68,000	79,000	17,000	95,000	2,77,000
b) On-site Bulk Systems	nil	1,10,000	2,00,000	35,000	3,00,000	6,50,000
2.2 Blasting Accessories (BAs) :						
a) Det. (mil. No.)	160	260	260	120	160	960
b) Det. Fuse (mil. m)	7	90	100	13	160	370
3.0 No. of Licensed User:	240	3250	1100	1120	2000	7710
4.0 No. of Licensed Outlets:	30	1170	220	310	550	2280
B) Accidents (2008 - 2012)						
5.0 Number of Accidents : [No. / Fatality (F) / Injured (I)]	2008-09 No. / F / I	2009-10 No. / F / I	2010-11 No. / F / I	2011-12 No. / F / I	2012-13 No. / F / I	Aggregate No. / F / I
5.1 Manufacture						
• Fixed Plant						
HEs	Nil	Nil	Nil	Nil	Nil	Nil
BAs	1 / 2 / -	6 / 2 / 8	6 / - / 6	7 / 4 / 5	9 / 6 / 15	29 / 14 / 34
• On-site Bulk	Nil	Nil	Nil	Nil	Nil	Nil
5.2 Storage	Nil	1 / - /-	Nil	1 / 1 / 1	1/ - /-	3 / 1 / -
5.3 Transportation	Nil	Nil	3 / 4 / -	1 / - / -	Nil	4 / 4 / -
5.4 Misc.(unauthorized possession)	1 / 9 / 20	1 / - / 9	Nil	Nil	Nil	2 / 9 / 29
5.5 Grand Total	2 / 11 / 20	8 / 2 / 17	9 / 4 / 6	9 / 5 / 5	10 / 6 / 15	38 / 28 /63

b) Mandatory 'Safety Management Plan (SMP)' by every manufacturing unit which includes a detailed Hazard Operabiity (HazOp) analysis of hazard identification, risk analysis and control, to be periodically monitored by 'Safety Audit' conducted either in-house or by an external auditor.

c) Another related significant provision is the mandatory submission of the SMP to the local civil administration authority, thus not only reinforcing greater accountability of the Operator(s) but simultaneously also bringing the explosives hazard profile specific to a particular unit / operation (s) in the public domain.

Though the above progressive measures have significantly, brought in greater specificity and accountability in safety management, there are gaps that need to be addressed, as follows:-

i) The prescribed SMP needs to be supplemented with a standardized operating procedure / model for risk assessment. To give one example, there is a provision of 'man-limit' and 'explosive-limit' in a process buildings, whereas, there is no accompanying analytical prescribed basis for establishing these limits ? Currently, these limits are often 'need-based' and not 'risk-based'.

ii) Further, there is an urgent need to develop a comprehensive 'Database' representative of different explosives related activities of the explosives industry, including trends in individual fatality rates from accidents in different situations vis-à-vis the efficacy of the on-going measures taken for safety.

d) A conceptualized integrated frame work of risk analysis, (see figure 5), is proposed which could statutorily supplement the prescribed SMP in the Explosives Rules - 2008, and as importantly, further harmonize the safety protocol under the present dispensation with the best global practices.

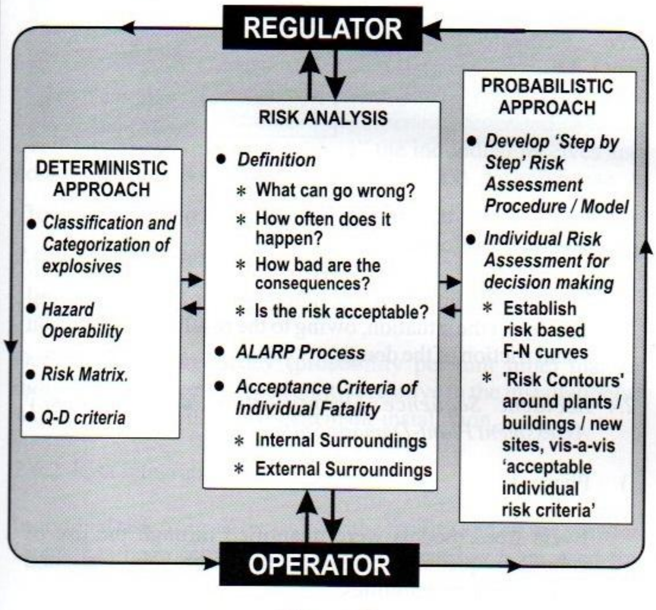


Figure 5

The model envisages an ongoing synergic collaborative framework between the 'Regulator' and the Operator(s), rooted in a strong 'data base' developed for the purpose.

- Editor

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Annexure - 1

Abstracts from the paper "Quantified Risk Assessment for Plants Producing and Storing Explosives, by Ioannis A. Papazoglou, et al" 2006.

1.0 Brief Description of Installations Investigated :

- Production of Nitro glycol
- Production of Detonating Cord
- Dynamite Production
- ANFO Production.

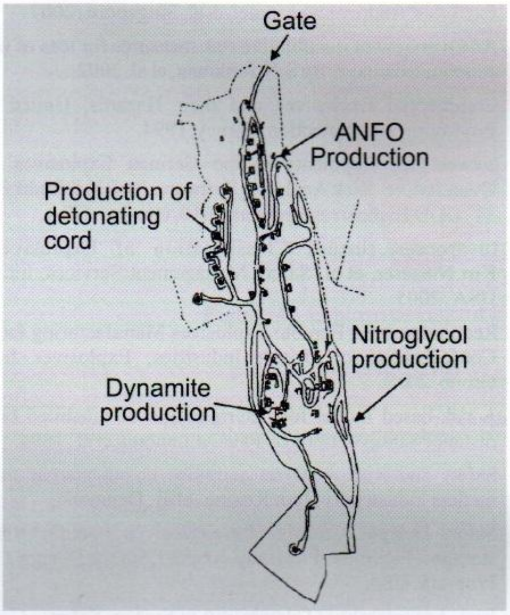


Figure 1 - General outline of the plant

2.0 Assessment of Plant Damage States and their Frequency of Occurrence :

In the first phase of QRA, the possible damage states of the plant along with the accidents sequence that can cause them are determined. Next, the frequency with which the occurrence of such states are expected is assessed.

2.1 *Hazard Source Identification.*

Three major hazard sources were distinguished.

- ◆ Various storage buildings of explosives.
- ◆ Production units of ANFO, Detonating cord, PETN , nitro glycol and dynamites (unit Tellex, mixing, Sleevex, LD-EX, Rollex), packaging of cartridges.
- ◆ Transfer routes of explosives from production to storage magazines.

Production capacities, storage capacity of magazines and transfer routes.

2.2 *Accident Sequence Determination*

2.2.1 Initiating Events (IE)

Accidental initiation of explosives is possible from a number of stimuli; the most important are : shock wave, mechanical, heat, chemical instability/reactivity, electrical and electro-magnetic energy, etc.

2.3 *Accident Sequence Modeling*

Each and every of the identified initiating events, safety barriers were in place to impede these events from resulting into an immediate cause of detonation. Models, event trees were developed to simulate the logical interconnection of IEs and successes and failures of the safety barriers into sequences. For example, a typical event tree constructed for the initiating event 'high level of dough in the feeding hopper' is illustrated below :

High level of Dough	Sensor	Operator	Consequences
			1.Safe
	No	Yes	2. Safe
		No	3. Explosion owing to friction

Figure 2 - Event tree for the initiating event "high level of dough in feeding Hopper"

(An explosion will occur if both sensor and operator fail to detect the situation, owing to the resultant suppression and friction of the dough)

2.4 *Accident Sequence Quantification and Frequency Assessment Plant-Damage States*

i) Phase -1

Event trees models were quantified through the use of generic frequencies, hardware failure probabilities, and human error probabilities.

ii) Phase II

Since the installation had access to the accident records of similar installations world wide and for a substantial number of years, a simple statistical estimation of the frequency of explosions was performed for each plant damage state, for each location of the installation where explosives is stored or processed, presented in the table below :-

Frequency of explosion in units of the (year^{-1})

- ★ Dynamite mixing (Bldg. 45) $6.0x10^{-3}$
- ★ Dynamite cartridging (Bldg. 46, 60 & 61) $1.1x10^{-2}$
- ★ Packing of dynamites (Bldg. 67 & 68) $5.0x10^{-3}$
- ★ Drying of PETN (Bldg. 23) $4.0x10^{-3}$
- ★ Spinning of PETN (Bldg. 13 & 14) $3.0x10^{-3}$
- ★ Coating detonating cord with PVC (12 & 25) $6.0x10^{-3}$
- ★ ANFO production (Bldg. 2) $9.0x10^{-4}$
- ★ Dynamite or detonating cord storage (Bldg. 6, 7, 8, 15, 26, 50, 56, 58) $4.5 x 10^{-4}$
- ★ Storing of nitroglycol (Bldg. 44) $3.0x10^{-3}$
- ★ Transportation of explosives $2.0x10^{-3}$

Comparison of the event tree quantification with the statistically derived frequencies of explosion indicated that the two independent calculations were in good agreement.

2.5 Consequence Assessment

Only consequences of overpressure were considered, viz, estimation of peak overpressure, estimation of impulse, Dose overpressure (the integrated, over time, exposure of an individual to the extreme phenomenon generated by the overpressure determines the "dose" the individual receives and consequently the severity of the consequences), dose response

2.6 Risk Integration

2.6.1 Individual Risk

Defined as the frequency (probability per unit time) that an individual at a specific location(x,y) relative to the installation(s) will die as a result of an accident in the installation.

2.6.2 Risk Integration and Conclusions

Individual risk from all the units of the facility and all the transfer routes has been estimated. A GIS platform has been used for presenting individual risk and all relevant plant information such as :

a) buildings and magazines (storage warehouses),
b) barricades of magazines and other buildings,
c) transfer routes within the plant,
d) quantities of explosives manufactured, stored and transported within the plant and their variability,
e) frequency of explosion for each hazardous source,
f) individual risk resulting from explosion of static explosives
g) individual risk resulting from transfer of explosions within the plant, and
h) total individual risk resulting from all possible explosions. Figure 3 presents total individual risk from the explosives plant. Risk is equal to $1.0x10^{-3}$/y in a distance of 270m from the center of the plant, $1.0x10^{-4}$/y in a distance of 340m from the center of the plant, $1.0x10^{-5}$/y in a distance of 360m, $1.0x10^{-6}$/y in a distance of 390m from the center of the plant.

The GIS platform is very useful for risk calculations since individual risk can be calculated and depicted in case storage capacities of magazines alter, or transfer routes of explosives are modified.

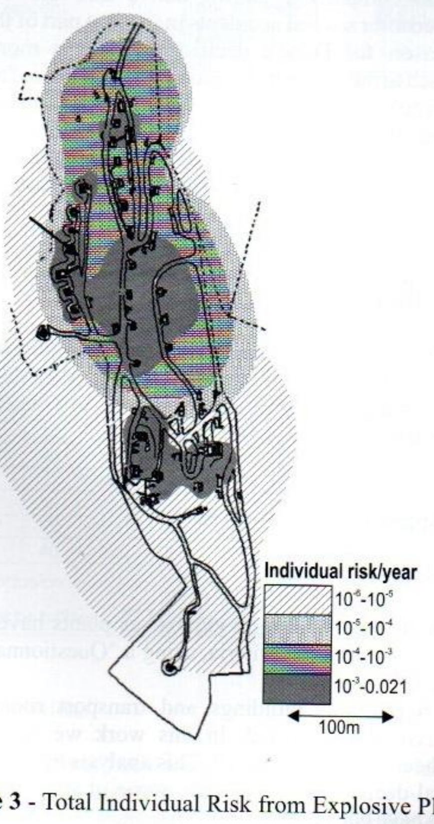


Figure 3 - Total Individual Risk from Explosive Plant

SUPPLEMENT

Aspect of Planning of an Explosives Plant with Consideration to Internal and External Safety Distances

Shri Per A. Krogstie

Dyno Industries A-S, Explosives Division, Norway, 1983

1.0 Background

The number of fatalities in the production of commercial NG-explosives in Western Europe over the last 15 years, and from an estimate of the number of employees, the number of fatalities per 100 million working hours can be calculated.
For comparison, the official Norwegian .statistics for 1970 are shown :

- Explosives production in Western Europe
  50 fatalities/100 million working hours
- Mining industry, Norway .
  35 fatalities/100 million working hours
- Total industry Norway
  5.5 fatalities/100 million working hours

The comparison shown above and the reactions that occurred after several accidents in the first part of the 1970's was the reason for Dyno's decision to start a more systematic approach to the problem of reducing the number of accidents.

Dyno's explosives plants are all placed in populated areas less than 30 miles from Oslo. One of the first and most important tasks was therefore to find criteria vis-a-vis our surroundings. Up till now all our work has been based on the assumption that an accident will occur (probability =1)

2.0 Criteria

Dvno's criteria for external and internal conditions are shown in figure 1. This kind of criteria made it possible to plant and arrange our production and storage areas in a better way than the traditional quantity distance tables.

3.0 Applications of the Criteria

3.1 General Approach

A risk analysis of Dyno's explosives plants have been studied with respect to these criteria, using a "Questionnaire" shown in figure 2.

The various buildings and transport routes have been analyzed and classified. In this work we have also used a datasheet, shown in figure 3. This analysis has been the base for several decisions and changes, some of which are substantial, which have been carried out.

DYNO, CRITERIA VERSUS SURROUNDINGS

Figure 1

Fatality rate $P_f = 0.1 . 10^{-3}$

This is lower than the risk of being killed by fire in Norway.

Sr. No.	Surroundings	Max. Allowed Air Pressure	Min. Distance Due to Fragments
1.	Dwellings	50 mb	400m
2.	Public roads	80mb	2/3 x 1 i.e. 270m
3.	Shops	30 mb	3/2 x 1 i.e. 600m
4.	Schools, churches etc.	22 mb	2 x 1 i.e. 800m

The minimum distance due to fragments is based on maximum 1 lethal fragment per 56 m^2.

DYNO'S INTERNAL CRITERA

Fatality rate $P_f = 5 . 10^{-8}$

This is identical with the average value for Norwegian industry.

1. Departments who have no connection with the production and storage of explosives — 50 mb
2. Departments directly involved in production and storage of explosives — 100 mb
3. Production or storage departments dependant on each other, explosives under transportation, packed and protected explosives — 200 mb
4. Inside a production or storage department. People working inside building should not be exposed to air pressure higher than — 350 mb

   or to ground shock exceeding 8 g, velocity 3 m/sec.

   The people should not be exposed to fragments.

3.2 Work in the Gullaug Plant

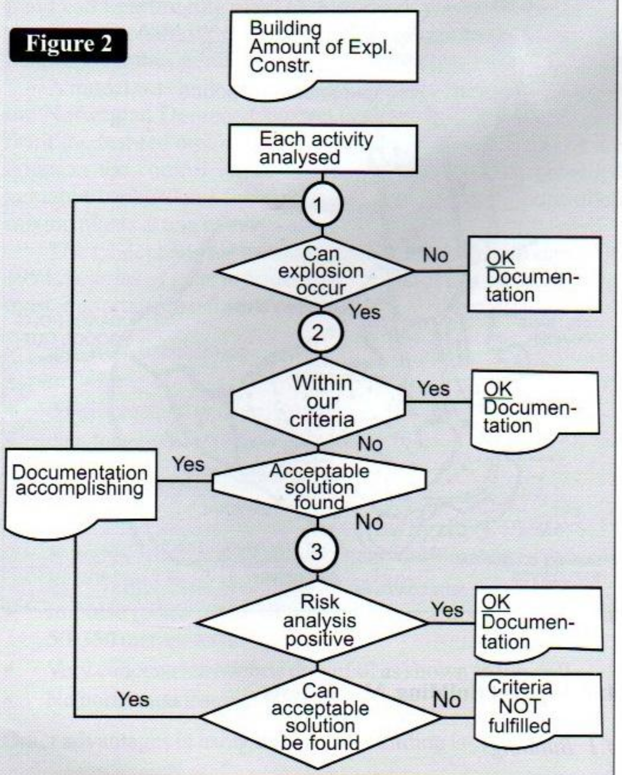
As the map in figure 4 shows, the Gullaug plant is situated on a peninsula.

Boundaries set up by the criteria versus the nearest dwelling, shops, schools, roads and factories are shown,
All explosives activities were situated on the part of the plant area outside these boundaries.

The quay with up to 400 tons and some magazines containing 50 tons each (sum 600 tons) were found not acceptable.

CHECK PROCEDURE, RISK ANALYSIS

Figure 2



The conclusion of the first stage was therefore that the Gullaug plant fulfilled the demands versus the surroundings, if the quay and the magazines were removed.

The next questions were whether the internal criteria were fulfilled, and if the remaining area satisfied our demands for the present and future concerning space.

Figure 5 shows how the plant was arranged when the work started.

The numbered areas were found not suitable to fulfill the criteria due to the distance to the workshops and roads. The amount of explosives in process in these buildings was too high and since there was no practical way of reduction the following major decisions were made.

- Production of TNT had to be stopped.
- Production of TNT slurry, ANFO and detonating cord had to be moved. This was taken into account in the new plant layout.
- The quay and the magazines had to be moved out of the plant area.

These projects are mostly finished by now. In the plant we have 3 categories of traffic.

- Personell
- Undangerous goods
- Dangerous goods

These categories will all affect the risk situation.

Personell transport represents a risk problem only if it goes through or stops in dangerous areas.

Transport of dangerous goods will be a problem by endangering the route.

This led to that several roads and routes had to be changed. New routings for personell transport (buses and private cars. parking, place) were introduced. In order to achieve rational transport of dangerous goods it was decided to build a sorting/intermediate storage terminal for finished products from where the goods are transported to the magazine area. This terminal has been in operation since early 1976 and consists of 5 igloos for 8 tons each.

DYNO INDUSTRIES A.S — **ANALYSIS OF INTERNAL CONDITIONS**

Figure 3

Building No. A 46 Function : Cartridging Remote Controlled Rolex	Terrain Profile. Scale:
DONOR PROPERTIES : Max. allowed amount : 100 kg Equivalent amount TNT, Q_1 : 90 kg	EXPOSED PERSONS : Max. Number: 3
Type of building, construction : Light wooden building surrounded by mount	(see exposed persons table)
Fragments : Distant : Much Nearby : Little	Sum: Number persons x exp. time per shift 1.7
Reduction factor for P_{max} due to type of building (50m distance) :	Average:Exposed number x exposed time per hour : 0.2
	Average manhours per deay for cleaning: 2
	Remarks:

Number of persons	1	2	3	4	5
Average time of exposure per shift	0.5	0.3	0.2		
Number of persons x time per shift	0.5	0.6	0.6		

ACCEPTOR PROPERTIES:

Neigh-bour-building no.	Same depart-ment?	Dista-nces meter	Q_1 (Q2) kg	$f=\frac{d}{3\sqrt{Q}}$	Pmax free charge mbar	Red. Factor donor	Red. Factor acceptor	Red. Pmax.
A-55	Yes	34	300	5.1	460	0.4	0.7	130
A-49	Yes	90	300	8.2	210	0.75	0.7	110
A-54	No	175	5400	10.0	155	1	0.9	140
A-56	Yes	35	720	3.9	680	1	0.9	610
A-73	No	325	45000	9.1	180	1	1	180
A-47	Yes	40	320	5.8	180	0.8	1	270

Remarks - conclusion

Criteria can not be fulfilled ☐ Criteria can be fulfilled ☐ Satis-factory ☐

3.3 Final Conclusions

The analysis which has been roughly described above led to a disposition plan for the area which is shown in figure 6.

As the plan shows the transport of personell and undangerous goods are led in one end of the plant and the dangerous goods are taken out in the other.

Further on the area has been divided into areas which give place both for the present production and for future activities. Among the borderline between the different areas we have planted trees which act as screens mostly for fragments.

Figure 4

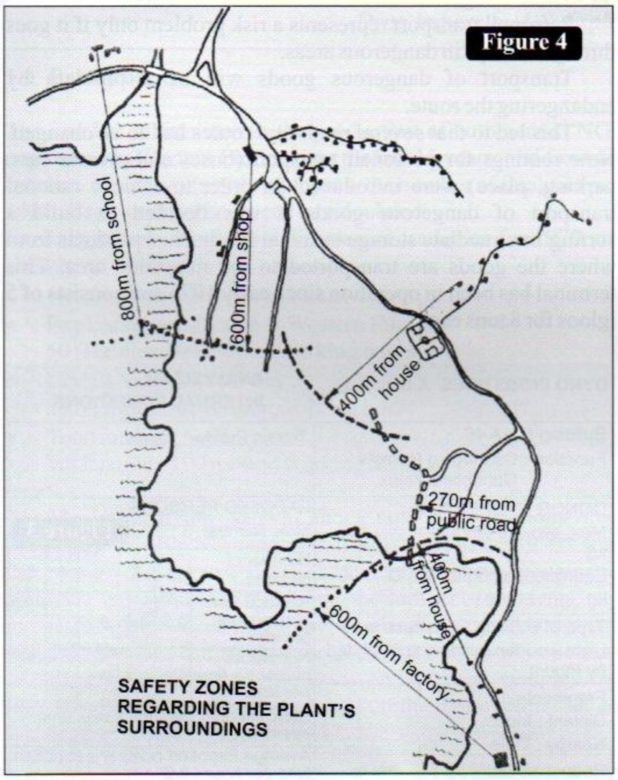


Figure 5

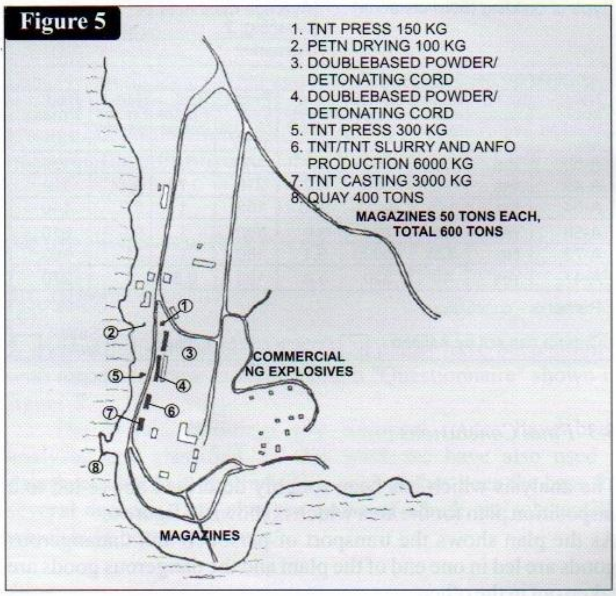
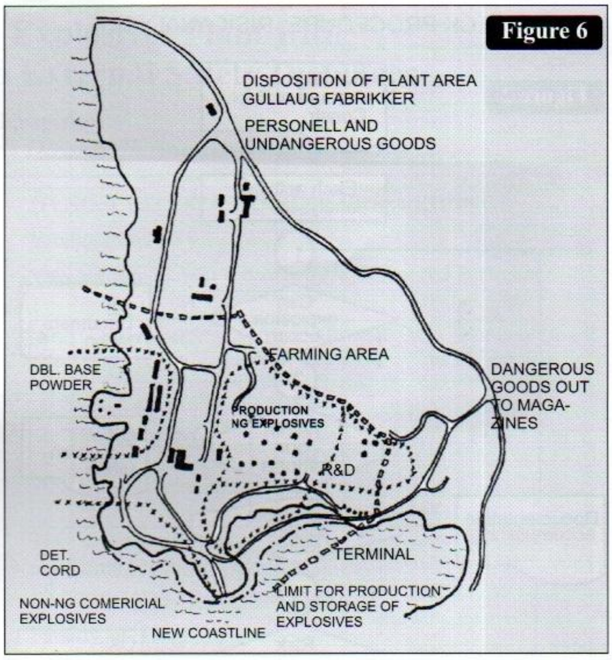


Figure 6



4.0 Types of Building, Model Tests

4.1 Buildings

Figure 7 shows in principle the various types of buildings used in the production areas and also indicated their place in time.

From a safety point of view the totally buried, concrete building and the steel houses are very much alike. Both have a well defined effect in reducing the shock pressure in the area close to an explosion compared with the conventional mounded building. In the matter of debris the steel house is to be preferred.

When the question comes to arrange a layout for an explosives production plant where space is limited these constructional properties combined with our kind of criteria are very valuable.

The development of these constructions started earlier than our risk analysis and from other motives. Without this work, however, we would have met much bigger problems in satisfying our internal criteria.

4.2 Model Tests

Our model tests can be separated in 3 separate parts :

- Tests referring to the cylindrical/concrete construction.
- Steel house tests.
- Spot tests to investigate special constructions and layouts.

As shown in figure 7 the cylindrical concrete building type was taken into use in the late 1960's. After having built 1 mixing plant and 1 cartridging plant of this type, it was decided to make a model test on the latter in order to investigate more closely, the condition for the operators in their control room.

A model was built in scale 1:10. The tests was carried out by the Norwegian Defence Construction Service. The conclusion from the test led among other things to a reinforcement of the doors in the control room. Data from this test also provided valuable background for the building of 2 remote controlled mixing plants at one of our plants,

The model tests for the double walled steel house started in 1971. A series of tests in scale 1:10,1.4 and 1:2 were made. The most important questions were

- pressure distribution
- impulse
- debris; vertical and horizontal,
- data for constructional calculations

The tests gave us the following

- Pressure distribution as shown in figure 8 (Scale 1:2). Roughly the pressure at a distance of 10 meters is reduced by 80% and from 50-350 meter, by 30%
- Impulse reduction at 10 metres distance about 70% and at 50-350 metres 40%.
- Very concentrated debris downfall as shown in figure 9.
- No horizontal fragments.

Other advantages in using this type of building is

- Compact layouts which leads to cheaper transportation systems.
- Simple foundations see figure 9.
- Flexibility in building and moving plants.

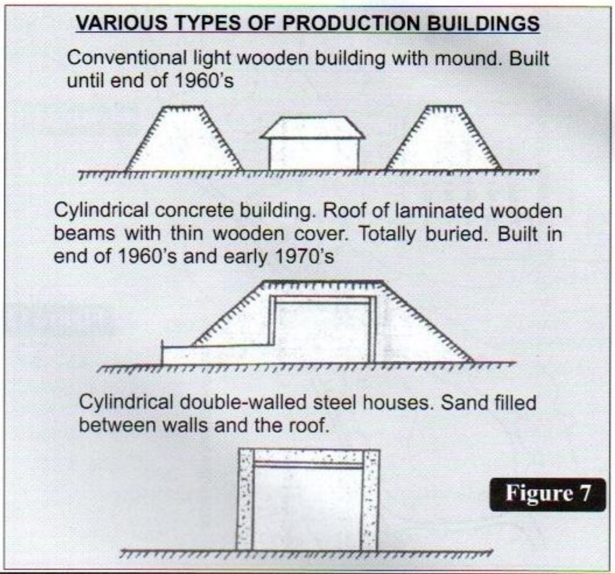


Figure 7

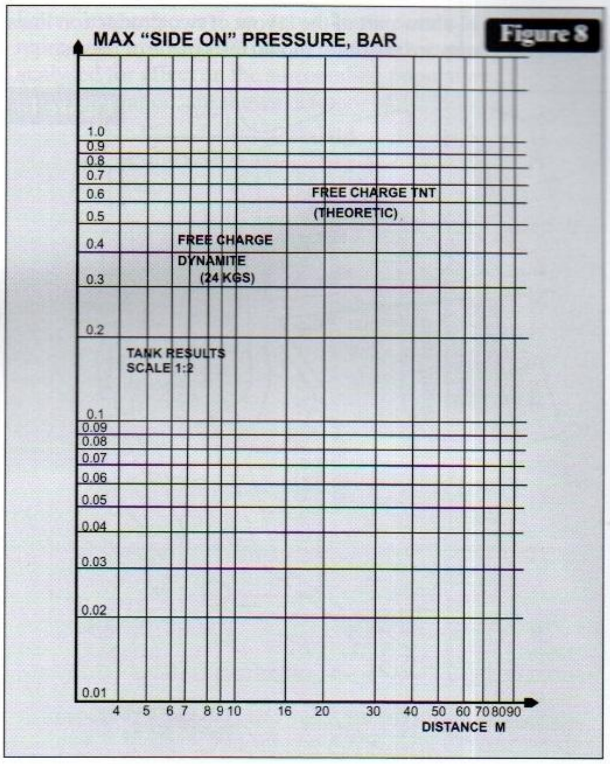


Figure 8

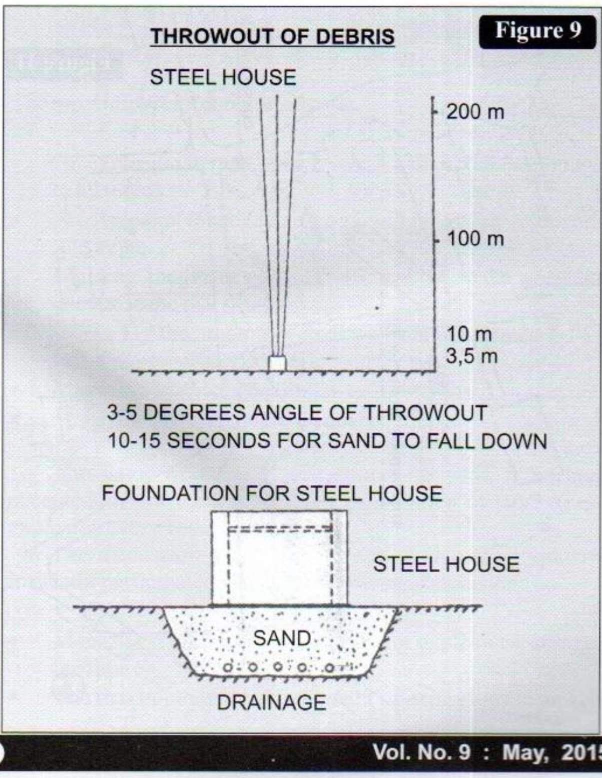


Figure 9

Figure 10 and 11 show part of the layout of two production lines at one of our plants are results of model tests made of theses.

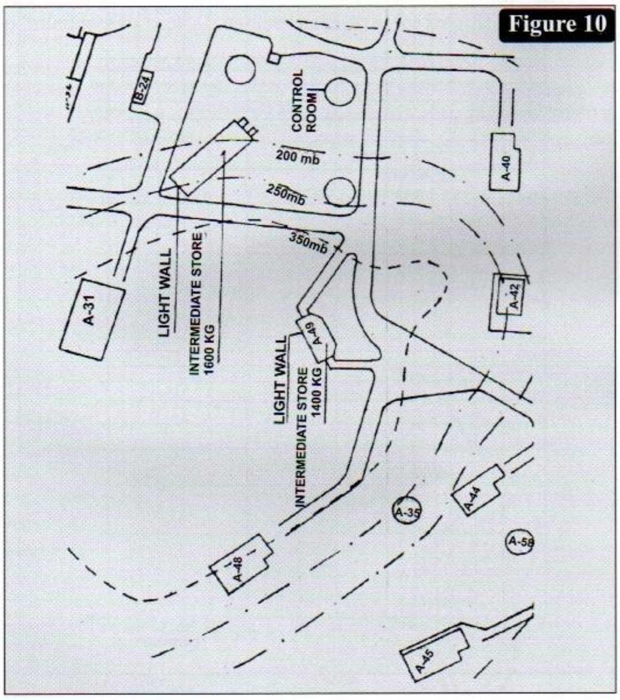


Figure 10

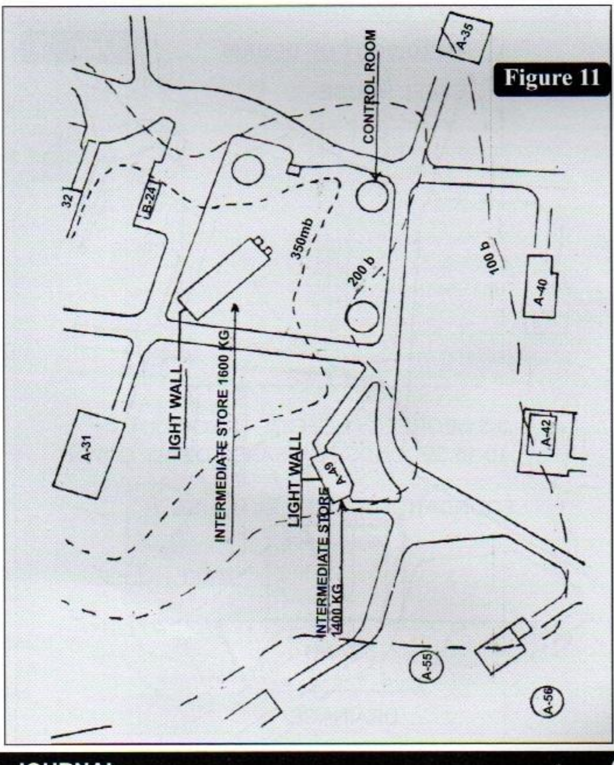


Figure 11

The problem was as follows:

In order to achieve a satisfactory regularity in production it was necessary to introduce a buffer storage of explosives between the mixing and catridging operation. The buffer sizes were 1:400 and 1:600 kg. The space available was restricted and it was therefore decided to run a series of model tests in scale 1:10 of various constructions in order to mine the pressure propagation. The results led to a construction which give marked pressure reduction in certain directions which again make it possible to arrange the production line as shown.

When planning our pilot plant, we also run a series of model tests in scale 1:14 which led to the construction and layout we have today. Generally speaking model tests are looked at as a very useful tool of determining possible layouts and constructional details.

5.0 Storage of Explosives

5.1 General Background

Our main storage area is placed in a valley about 3 Km from the plant. Figure 12 shows a map of the magazine area. The magazines numbered 1-5 are of the box type and were built in the 1960's. The magazines 7-10 are of the igloo type and were built in 1974/75 and represented the first step of moving the magazines out of the plant area. The dotted magazines 11-17 are future magazines.

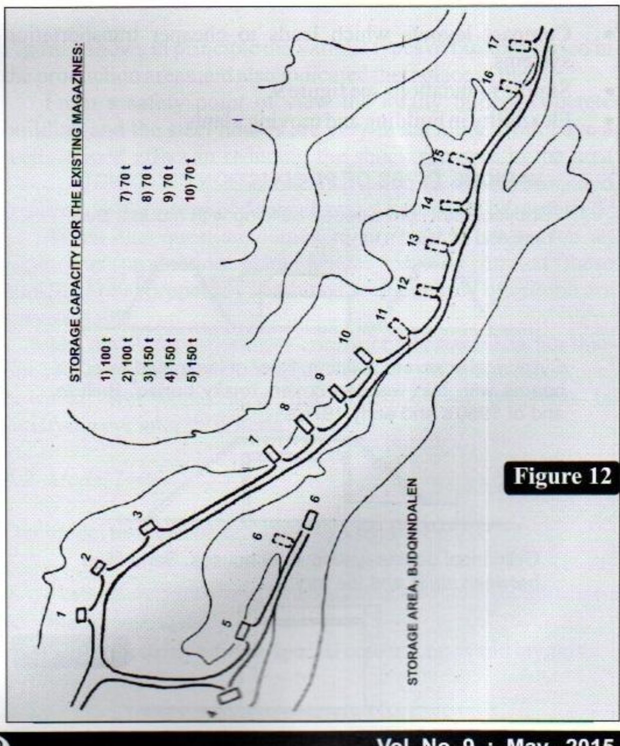


Figure 12

In order to allow a further expansion of the magazine area (11-17) the Norwegian Explosive Inspector demanded that a risk analysis should be made. The Swiss consultant firm Basler & Hofmann were hired for his job, and the work started late in 1976. The analysis was dived in 2 stages:

- Is it recommendable to build further magazines area and what mount of explosives could be stored ?
- What could be the most probable causes for an explosion.

5.2 Result of the Analysis, Stage 1

Figure 13 shows the principles for the approach to the analysis, and figure 14 defines the terms "individual risk" and "group risk".

Figure 13

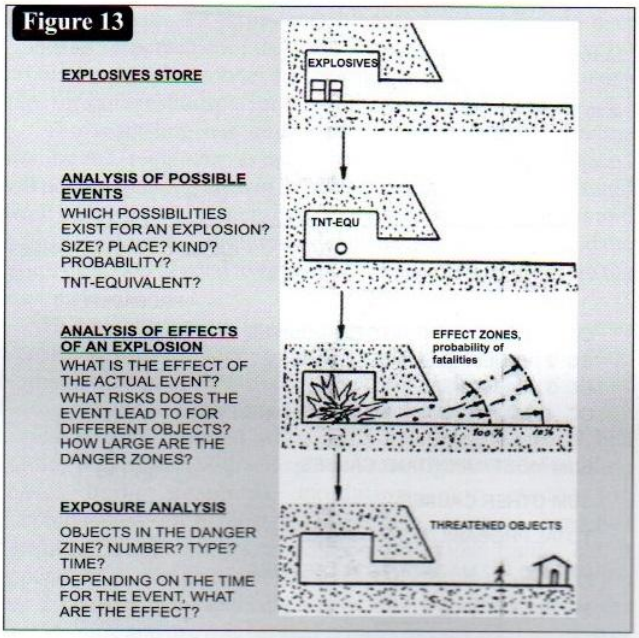
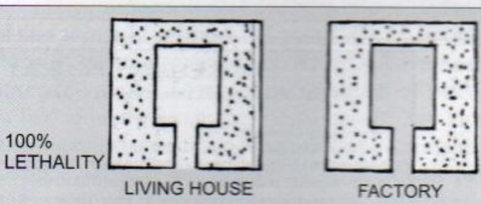


Figure 14



	LIVING HOUSE	FACTORY
NUMBER OF PERSONS PRESENT	2 (ALWAYS THE SAME PERSONS)	40 (ALWAYS THE SAME PERSONS)
PRESENCE	90%	25%
PROBABILITY OF AN EXPLOSION	W_E	W_E
MAX. INDIVIDUAL RISK *	0,9 W_E	0,25 W_E
GROUP RISK **	1,8 W_E	10 W_E

* INDIVIDUAL RISK - PROBABILITY OF LETHALITY x AVERAGE PRESENCE PER INDIVIDUAL

** GROUP RISK - PROBABILITY OF LETHALITY x AVERAGE NUMBER OF PEOPLE PRESENT

Every magazine and in some cases a sum of 2 magazines represents an "event", i.e. a potential explosion and were analysed for effect on the surrounding population. The result of these calculation, are shown in figure 15.

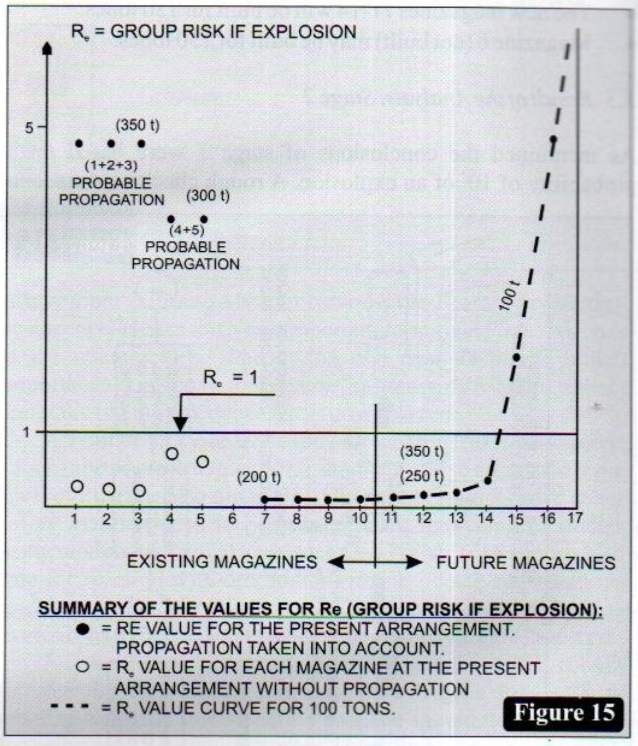


Figure 15

The most important conclusions are:

- An explosion in magazine 1, 2 or 3 will probably propagate to all three.
- An explosion in magazine 4 or 5 will propagate to the other magazine.
- Building magazines 11, 12, 13 and 14 make very little change in the risk situation.
- Increasing the amount of explosives in magazines 7-14 up to 250-350 tons has little effect on the risk
- Magazine 15 should be limited to 70-80 tons.
- Magazines 16 and 17 should not be built.

The value of Re = 1 corresponds to what is normally accepted in Switzerland with a probability of 10-3 (i.e. 1 explosion every 1000 year).

The discussion of the report, where also the Explosives inspector participated, led to the following conclusion:

- Magazine 2 and 4 will not be used for explosives storage in the future.
- The maximum allowable amount of explosives in an igloo

magazine should be set to 150 tones (with reference to the ESKIMO program).

- The allowable amount of explosives in magazine 7-10 was increased from 70 to 100 tones.
- The new magazines 11-14 will be built for 150 tones.
- Magazine 6 (not built) may be built for 150 tones.

5.3 Result of the Analysis, Stage 2

As mentioned the conclusions of stage 1 were based on a probability of 10^3 of an explosion. A rough check was made in this stage.

Stage 2 consisted of a very detailed and thorough analysis of possible causes and probabilities in order to get as good confirmation of our earlier assumptions as possible.

Figure 16 shows the model for the analysis. All the different links in the various chains of events were studied. The result of the analysis is shown in figure 17.

The conclusion was that the probability at the time of the analysis was too high, but that it can with simple means be lowered to an acceptable level. This work will very soon be finished.

Figure 16

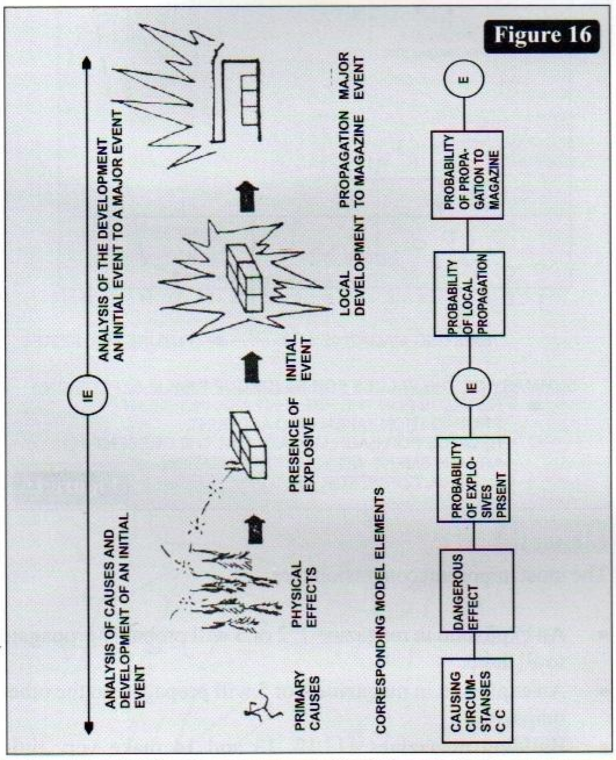
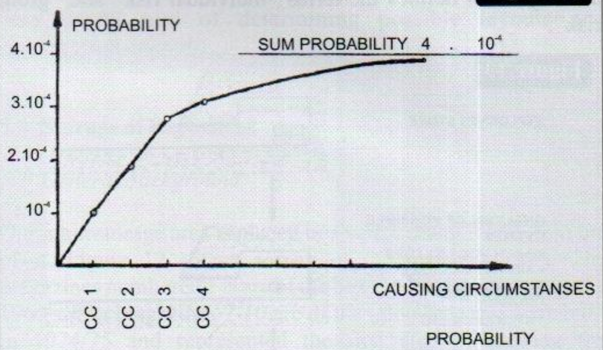


Figure 17



	PROBABILITY
CC 1 : FORKLIFTER HITS EXPLOSIVES	$10 \cdot 10^{-5}$
CC 2 : FAULTY ELECTRICAL SYSTEM	$9 \cdot 10^{-5}$
CC 3 : SABOTAGE	$9 \cdot 10^{-5}$
CC 4 : MAINTENANCE ACTS (WELDING ETC.)	$3 \cdot 10^{-5}$
SUM MOST IMPORTANT CAUSES	$3{,}1 \cdot 10^{-4}$
SUM OTHER CAUSES	$0{,}9 \cdot 10^{-4}$
TOTAL PROBABILITY PR. MAGAZINE	$4 \cdot 10^{-4}$

WITH 10 - 12 MAGAZINES IN THE AREA :

PROBABILITY ~ $5 \cdot 10^{-3}$

COVER FEATURE & SUPPLEMENTS

SUPPLEMENT

Valedictory address by Dr. E.G. Mahadevan, at the "Workshop on Explosives for Mines-Safety issues", conducted by the DGMS and the Explosives Manufacturers Association on 24th March, 2015, at Hyderabad

Dr. E.G. Mahadevan
Patron / Chairman, Governing Council, Visfotak

Responsibility for delivering a safe explosive product to the mines rests with the Explosives manufacturer while end user (mines) is responsible for the correct/safe use of the explosive by utilizing trained personnel for blasting and following statutory rules for storage, transport and handling.

The workshop has already discussed in great detail the training and regulatory aspects of explosives useage and hence I will not be repeating them in my presentation. Rather my talk will dwell on the intrinsic safety built into the explosives systems and industrys efforts to continuously evolve safer explosives and the future direction needed to further enhance safety levels from the existing levels.

Historically up to 1970 Nitroglycerine based explosives were solely used in underground and opencast mines for blasting. Number of accidents were reported due to the high sensitivity of Nitroglycerine to FISH (friction, impact, static and heat). Many accidents were reported when drilling relief holes (drill bits coming into contact with unexploded cartridges), while handling (cases being dropped), exudation /auto exothermic decomposition of explosives in storage, tamping hardened cartridges into boreholes, generation of noxious fumes, etc. It appears from examination of data on accidents in mines over the last 2 decades and especially since 2004 when NG explosives manufacture and use was banned in India by the CCE that most of the types of accidents mentioned above have been eliminated to a great extent and this coincides with period post 2004 when only AN based explosives (slurries, emulsions, AN/FO) have been used for blasting in the mines. Stringent enforcement of safety regulations as laid down by statutory authorities has also contributed to the overall reduction in the number of accidents. This is particularly evident if the frequency of accidents per output of ore or total amount of explosives consumed is used as a yardstick since there has been an explosive (no pun intended) growth in the consumption of explosives with the advent of bulk loaded explosives and the steep increase in open cast mining. However there are still a few matters of concern that need to be kept in mind

All Ammonium Nitrate based explosives while not much influenced by FISH in short inputs are adversely affected by direct fire and in confinement can lead to explosion and create a hazardous situation. Worldwide most explosions involving Ammonium Nitrate /AN explosives have fire as the starting occurrence. Hence it is very important to mitigate this risk both at the manufacturers and at the end user. Generally much importance is given to the adverse influence of friction ,impact and static but the risk due to fire is downplayed.

All initiating systems be they Detonating fuse, nonelectric shock tube or electric/electronic detonators also come under the spell of FISH as also direct fire. Claims of products with better safety margins need to be substantiated by scientific studies using modern analytical tools such DSC/DTA/TGA. This is also true for reaction with ore bodies and auto catalyzed reactions leading to premature blasting. Such accidents are many where even AN based explosives like slurries, emulsions are involved.

A lowering of the hazard due to influence of FISH if built intrinsically into the initiator system will go a long way in creating a greater safety margin and this should be taken up at top priority by the manufacturers. The influence of stray current, energy from radio frequency waves is another hazard which needs to be guarded against by providing appropriate design in the electric/electronic detonators. While the use of nonelectric system and electronic delay systems has brought in a greater degree of safety during blasting and improved the blasting efficiencies most of them use at the business end filled shells containing PETN and ASA (azide /styphnate/aluminium). A look at the number of accidents involving these products and scientific data of risk due to FISH shows the problem arises due to the sensitivity of ASA and this needs to be taken care of. Already attempts to replace ASA by other less sensitive chemicals have succeeded and in India 2 explosives manufacturers are manufacturing such detonators. I strongly urge that the explosive industry for its own and end users safety find safer alternatives to ASA based detonator. This may take a few years but in the interim a higher degree of safety against static, stray current and RF energy (which are the main causes of premature and unauthorized blasts) can be obtained by use of VA/exploding bridge wire type detonators (group 3 type European standards) instead of the current design of detonators (which are group 1 type) in all initiating systems used in the organized sector. This will also protect the enduser from unauthorized low energy initiation from sources like torch cells/mobile telephones.

SCIENTIFIC / TECHNICAL PAPERS

IMESAFR Version 2.0 : A Next Generation Tool for Managing Risk Associated with Commercial Explosives Operations 2014 Update




John Tatom
A-P-T Research, Inc

Michael Swisdak
A-P-T Research, Inc

Lon Santis
Explosives Risk Managers, LLC

Tyler Ross
A-P-T Research, Inc

Abstract

SAFEX does not promote any product commercially. This Paper is published as a Topical Paper because of its contribution to the domain of quantitative risk assessment. The tool it describes, IMESAFR, is very relevant to the commercial explosives industry using algorithms for debris and blast which many consider as state of the art for this type of application. IMESAFR (IME Safety Analysis for Risk) was developed and released by the Institute of Makers of Explosives (IME) and A-P-T Research, Inc. (APT).Previous versions of this software program have been described in published papers and have been compared to available real-world test and accident data. IMESAFR was first released in 2007. The most recent edition of the software, IMESAFR Version 2.0, was released in February 2013.

Version 2.0 incorporates many new features and advanced tools. Some of the new features in Version 2.0 include:

- *Graphical Interface System (GIS) to help map and visualize facility layouts and input in order to display the software results visually.*
- *Both Imperial (English) and SI (Metric) versions.*
- *Reduced algorithm conservatism in many aspects of the Potential Explosion Site (PES) and Exposed Site (ES) models.*
- *The ability to use GIS information to check compliance with quantity-distance (QD) standards.*
- *The ability to separate or "turn off" the contribution from the uncertainty model that is designed to conservatively increase the estimated risk hazard due to uncertainty in the input and natural variations in circumstances.*

These changes and new features, along with many others, are discussed and demonstrated.

1.0 Introduction

Around the world, wherever explosives are manufactured and stored, safety is of paramount importance. In order to reduce the risks associated with explosives, these risks must first be understood. Advances in explosives safety, in both defense and industry, need to be shared internationally.

The IMESAFR (Institute of Makers of Explosives Safety Analysis for Risk) software tool, which was based on the SAFER (Safety Assessment for Explosive Risk) program [Reference 13], has been commercially available since 2007. Although it was originally designed for use by the commercial explosives industry in the United States, it is in use around the world. The IMESAFR 1.0 Development Team included representatives from IME member companies and stakeholders from the government and the International Society of Explosives Engineers (ISEE). The IMESAFR Development Team began consulting with APTon development issues in 2005. This team used the SAFER model as a baseline methodology and developed new models to apply to the commercial explosives industry.

Generally, the effects and consequences algorithms in IMESAFR have been recognized as state-of-the-art and are supported by test data. However, the initial releases of IMESAFR (Version 1.0, Version 1.1 and Version 1.2) have had several limitations that have restricted the usage of the program outside of the United States. The software user-interface requires a fair amount of manual data entry, and visualization of

The original version of this paper was presented by the authors at Parari 2011, the 10th Australian Explosives Ordnance Symposium, which was held in Brisbane, Australia, from 8 to 11 November 2011. It was printed as SAFEX Topical Paper No 07/2011 with the kind permission of the Symposium Organisers. This 2014 update was prepared to incorporate updates to the software.

the calculated risks was never the focus of the design. Also, potential users have often asked for a metric-unit option. Finally, the probability of event (P_e) could not be altered (or entered) by the user, which limits the event frequency to only those built into the program.

In 2006, at the 32nd

Department of Defense Explosives Safety Board (DDESB) Seminar, APT and IME began publishing the details of IMESAFR [Reference 1], including its relationship to SAFER [Reference 2]. The description was updated in 2007 by a paper presented at Parari [Reference 3] that included additional details of the IMESAFR models.In 2008, at the ISEE Conference [Reference 4], IME presented a paper that worked through three hypothetical Quantitative Risk Analysis (QRA) scenarios.Later in that same year, APT and IME presented a paper at the 33rd DDESB Seminar [Reference 5], which included real-world examples of regulatory approvals using IMESAFR.

In 2010, APT and the US Army Corps of Engineers performed a comparison between the IMESAFR predicted debris distribution for a truck and test data collected on the ISO-1 and ISO-2 test programs [Reference 6]. This comparison effort found encouraging agreement between IMESAFR and the test results, and was continued and updated later that year [Reference 7].

In 2010, IME and APT performed comparisons between IMESAFR, DIRE (Death and Injury Resulting from Explosions), and the original data used by Assheton to set intra-plant distances [Reference 8]. Dire is a consequence tool that assumes that the event has occurred. This study demonstrated conservative results for IMESAFR for close-in exposures when people were in the open; the study was updated later in the same year to include people in buildings [Reference 9].Finally, in 2011, APT and IME compared IMESAFR predictions to a recent Australian accident [Reference 10, 11], with the software again demonstrating conservative results for people very close to explosive events.

Based on these studies, IME and APT proceeded with the development of the next generation of the IMESAFR tool. IMESAFR Version 2.0 was developed between 2011 and 2013. It was released in February 2013.

Due to the algorithm updates and host of new features in IMESAFR, an extensive series of sensitivity studies was conducted between 2012 and 2014. These studies serve to ensure that new features perform as expected, algorithm updates produce logical answers throughout a range of input parameters, and verify that final risk answers are credible and include an established level of conservatism. These studies are described in Reference 16. A brief description is provided here.

The first series of sensitivity studies was completed in October 2012 as a "sanity check" of the QRA technical model. This study verified that the many individual components of the technical model, including updates and new features, interacted properly. Output was compared to explosives test data and accident histories, as well as output from previous releases of the software.

The principle sensitivity study effort occurred throughout 2013. This effort was designed to thoroughly test the interaction between facility types at varying ranges of explosives quantities and distances. More than 800,000 individual scenarios were analyzed and the results were organized into more than 14,000 graphs, providing an immense catalogue of data that can be used to find patterns in algorithm behavior and evaluate performance of new or updated software features. Results were organized by hazard mechanism (e.g., debris, overpressure, etc.) or facility type.

Analysis of the sensitivity study data has continued through 2014 in support of the IMESAFR 2.0 Development Team.

The sensitivity study process has provided the IMESAFR 2.0 Development Team with the opportunity to verify the behavior of the software and recommend improvements or corrections as needed. The improved models have been systematically tested to ensure that individual algorithm component behavior, as well as overall interaction between components, performs as intended. The sensitivity study testing created a large library of data that can be queried to further analyze the behavior of specific aspects of the models.

By testing the analysis algorithms across a wide range of input variables, confidence is built in QRA tools. The sensitivity studies led to the improvement of the tool as models were refined to work in better coordination with each other.

2.0 Relationship to SAFER

IMESAFR is a software tool that is based on the US Department of Defense (DoD) SAFER model, but is intended for use in the commercial explosives industry. IMESAFR supports the commercial industry in the same way that SAFER acts to enhance the DoD's ability to perform explosives facility siting.

The basic QRA concept of the "risk equation" is the same in both SAFER and IMESAFR:

$$P_f = P_e \times P_{f|e} \times E_p$$

In both programs, the probability of fatality (P_f) is the product of the probability of event (P_e), the probability of fatality given an event ($P_{f|e}$), and the exposure (E_p). However, IMESAFR incorporates several features specific to the commercial explosives industry, which are not available in SAFER. Similarly, IMESAFR does not contain some of the features in SAFER that are military-specific[Reference 1].Except for these differences, the algorithms in SAFER and IMESAFR Version 1.2 werevirtually the same.

It should be noted that the US DoD is moving towards a "one stop shop" for explosives safety siting, and will therefore consolidate the explosives safety programs that it supports. The ESS program [Reference 12] will be designed to access standardized installation databases of facility information; thus SAFER will be implemented as a module within ESS in order to take advantage of the interface designed to be used with the DoD database.

3.0 Development of IMESAFR V2.0

QRA software tools are moving to a geographic information system (GIS) interface, allowing import of site plans or aerial images. Since SAFER will be tied to GIS data in a proprietary format available only to the US military and its allied forces, IMESAFR and SAFER have reached a firkin the development road. IMESAFR V2.0 has been developed with an independent GIS interface that can accept many available formats of GIS information.

Additionally, IMESAFR V2.0 has introduced many user-defined parameters. Users of IMESAFR have repeatedly requested the ability to input their own values for many of the pre-defined parameters in the software.IMESAFR V2.0 now allows users to define parameters such as the P_e and the properties of explosive articles.

The IMESAFR V2.0 Development Team once again includes IME, APT, representatives from IME member companies and stakeholders from the government. APT began advising the IMESAFR V2.0 Development Team on explosives safety technical issues and software development issues for version 2.0 of the software in 2010. This team has once again used the SAFER model as a baseline methodology and has developed new models to apply to the commercial explosives industry.

3.1 New Interface

As mentioned previously, IMESAFR 2.0 includes a new graphical user interface (GUI) that allows for easier input data entry and better results visualization. This new GUI is GIS-based, but is completely independent of the ESS program. Rather than working from a standardized database like ESS, IMESAFR 2.0 has been designed to import any common type of data file or image in order to make setting up the scenario easier.

IMESAFR 2.0 can read from a datafile (registered image, jpeg, bitmap, etc.) And create a depiction of the scenario with a relative coordinate system, as well as a "tree structure" to represent the relationship between PES and ES entries. A basic sample screen from IMESAFR 2.0 is shown in Figure 1. This example shows two explosives facilities and an ES structure. The relationship between the facilities is shown in the panel on the left. A basic measurement grid is shown and can be utilized with or without background imagery.

IMESAFR 2.0 also has the capability to automatically determine building outlines, which the user can amend or supplement with manual entries. This feature can be used to quickly create a complex scenario based on an image file.

Whether the facilities are manually drawn or automatically recognized, the user provides a facility name and adjusts the properties of the structures. Properties include information concerning the explosives, activities, and people involved in the scenario. These steps can be used to create complex scenarios with many structures.

After the user finalizes the scenario details, IMESAFR calculates and displays the risks. A hypothetical set of results for a complex scenario is shown in Figure 2.This figure illustrates a scenario that has been developed based on an imported background image. Several key output features are represented in this figure. These will be discussed individually.

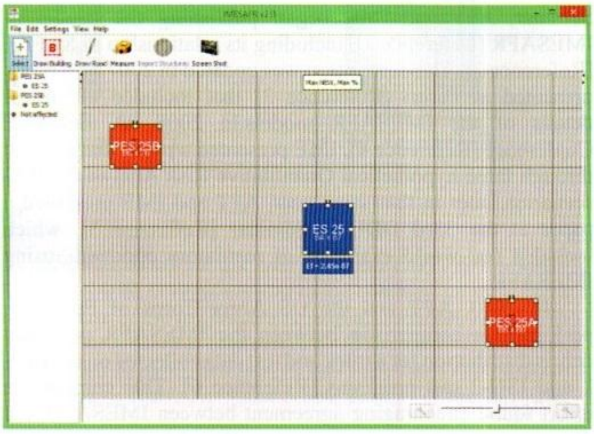


Figure 1 - IMESAFR 2.0 GIS Interface

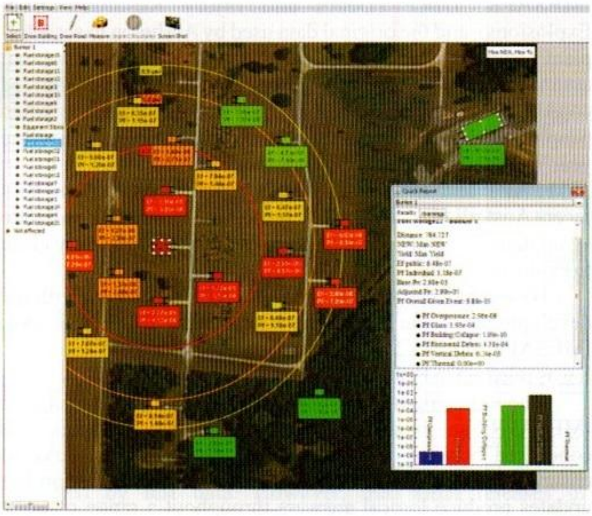


Figure 2 - Sample Complex Scenario with Multiple Types of Output Displays

First, the PES structure for this scenario is shown in the center of the concentric circles. Each of the surrounding exposed sites display results from individual risk calculations based on the hazards generated at the selected PES structure. Each ES is color-coded based on the relative amount of risk at each site. It can be seen that facilities that are near the PES have a greater overall risk. The calculated risk values are dependent on the details of each ES and the level of protection that they afford the occupants.

Second, the concentric circles around the selected PES represent overpressure levels. Debris hazards are represented in a different manner and will be discussed separately. The software will also display the Risk-Based Evaluation Distance (RBED), which illustrates the distance from a specific PES beyond which the hazards are low enough that exposed structures generally need not be considered.

Third, the software can illustrate details of each component of the risk calculation for a specific PES-ES pair in a pop-up window referred to as the Quick Report. This optional window provides calculation details for exposure, probability of event and the magnitude of hazards from individual hazard mechanisms (e.g., horizontal debris, overpressure, glass, etc.). This powerful display tool allows the user to gain important insight into which hazards are the greatest for a given scenario. This information is critical when analyzing potential risk mitigation strategies such as barricades or construction materials used at facilities.

In addition to the risk results shown in Figure 3, IMESAFR 2.0 can also display effects, such as the debris density (shown in Figure 3). In this scenario, the view has been extended to display additional area around the PES. The debris contours illustrate that the debris hazard from this PES facility is focused in orthogonal directions coming from the PES walls. IMESAFR 2.0 incorporates advanced debris density models that are based on analysis of explosives testing programs and historical accident data. These debris models will be described in more detail in a subsequent section.

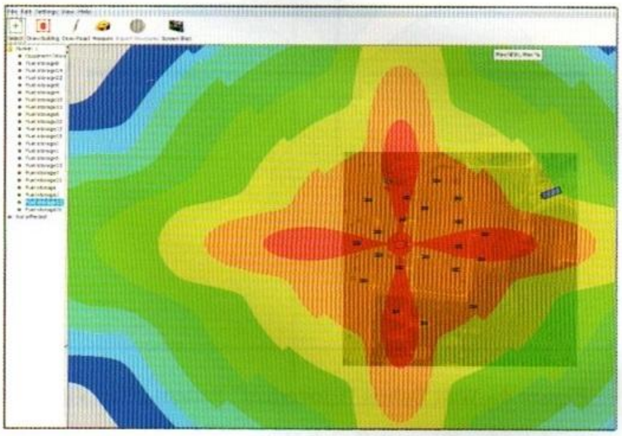


Figure 3 - Debris Density Display

With this type of information, the user may decide to rotate the PES such that the consequences change. This type of risk management is a key aspect of a visualization tool, and is an important capability of IMESAFR 2.0 (i.e., it is not just "pretty pictures").For example, in many scenarios, debris is the dominant risk factor and can be accounted for more accurately by taking into account orientation as well as distance. In the hypothetical case shown in Figure 3, the difference in risk between the green, yellow and red zones are orders of magnitude. Furthermore, exposed buildings at the same radial distance (but different azimuths) may have markedly different risks, which can be seen immediately in the debris density display.

Metric

Although the sponsors of both IMESAFR and SAFER are from the US, it has not gone unnoticed that other users would like the ability to work in metric units. IMESAFR 2.0 now incorporates this capability, and it is not be limited to simple conversion of inputs and outputs. A complete, parallel "metric engine" has been developed so users can extract information at the algorithm level from the program's System Log in metric units.

User-Defined P_e

In addition to the built-in activity types and their associated probability of event, IMESAFR 2.0 users are able to create customized P_e values that are more applicable to their scenario. This will allow the user to control that element of the risk equation; however, the software will flag the results as being affected by the user's choice (which is an input that the program cannot verify).

Conservatism Adjustments

In an effort to reduce potential undue conservatism in some situations and improve user control, IMESAFR 2.0 has implemented several changes to key algorithms and in some scenarios allows the user to "turn off" certain aspects of algorithms that are based on philosophical modeling decisions. These user-controlled options are referred to as conservatism "switches".

The following two lists give a brief description of each of the algorithm adjustments and conservative switches, with the IMESAFR/SAFER architecture step number given as a reference for those familiar with that nomenclature. The descriptions and terminology assume knowledge of the algorithms. Details for each of these adjustments or switches are provided in Reference 15.

It is important to note for the conservatism switches that in general the default mode is to calculate risks with all of these conservatisms "turned on" unless the user chooses to turn them off. Some scenarios, such as attempting to recreate a specific event, will be more accurately modeled with at least some of these conservative settings disabled. As with user-defined P_e values, if any changes to the default settings are made, the software will flag the results as being affected by the user's input decisions.

Algorithm Adjustments (Not user-selectable)

- Step 12 and 13 - primary fragment blocking: the default sequencing assumes that primary fragments escaping the remnants of the PES will have an unimpeded velocity; the more realistic treatment for robust structures would be to set the velocity to that of the applicable secondary debris. When applicable, IMESAFR 2.0 automatically adjusts the initial velocity of primary fragments based on the type of construction material of the PES. Escaping primary fragments are slowed to secondary fragment speed if the PES is a robust material such as concrete or masonry.
- Step 14 - nominal and dynamic mass distributions: the nominal mass distributions have been updated and the dynamic mass distribution routine is allowed to be more aggressive than the IMESAFR 1.2 model. A new, more realistic algorithm has been developed that allows the mass distribution to vary as the charge weight goes below the nominal weight, and to allow the dynamic mass distribution to shift more mass into smaller bins as the charge weight goes above the nominal weight. IMESAFR 2.0 contains various new nominal mass distributions and dynamic adjustment models for multiple material types. These updated values and new models are based on recent explosives test programs as described in Reference 15.
- Step 15 - debris probability functions: the high angle debris density distribution is treated as a Bi-Variant Normal (BVN) function in IMESAFR 1.2; IMESAFR 2.0 utilizes a toroid function which is more representative of test data. This new model creates less conservative debris densities in the immediate vicinity of the explosion, but higher debris densities downrange (see discussion for Figure 10 and References 10 and 11). This new model is applicable for specific PES components and debris types.
- Step 16 - low angle debris terminal velocity restriction: by rule, the calculated final velocity of the low-angle fly-through debris was not allowed to be lower than terminal velocity; this is physically impossible (unless the debris imbeds in the ground at the first point of impact), so the velocity decay is now allowed to occur naturally.
- Simplified Close-In Fatality Methodology (SCIFM) - change X_1 and shape of curve in transition region: the extent of the plateau region (determined by the X_1 parameter) and the shape of the transition region curve were set conservatively; more realistic X_1 values for each ES and a less conservative transition curve have been incorporated. This update is based on new analyses described in Reference 15.

Conservatism Switches (User-selectable)

- Step 17 - building response before debris arrival: in IMESAFR 1.2, the default sequencing assumption was that the ES has responded to the blast wave before the debris has arrived, thus (potentially) reducing the ES debris protection capability; a more probable sequence is that the ES debris protection has not been compromised by the blast wave before the debris arrives. This feature has been incorporated in IMESAFR 2.0 as a switch with four options that the user can select to determine which types of debris arrive before and after the potential effects of overpressure have been considered.
- Uncertainty decouple basic risk equation from uncertainty: by default, the uncertainty affects the base estimate of risk; IMESAFR 2.0 now shows uncertainty as a separate term, if so requested by the user.

Advanced Debris Density Predictions

For centrally-located charges in rectangular buildings, it has been observed that debris density is strongly affected by azimuth (i.e., the wall debris tends to go directly out "along the normals" and not "in the corners"). This effect, referred to as a cruciform or cloverleaf pattern, is an important factor in risk assessment when debris is a serious concern. A notional cloverleaf pattern is depicted in Figure 4, where the blue wall debris is ejected normal to each wall.

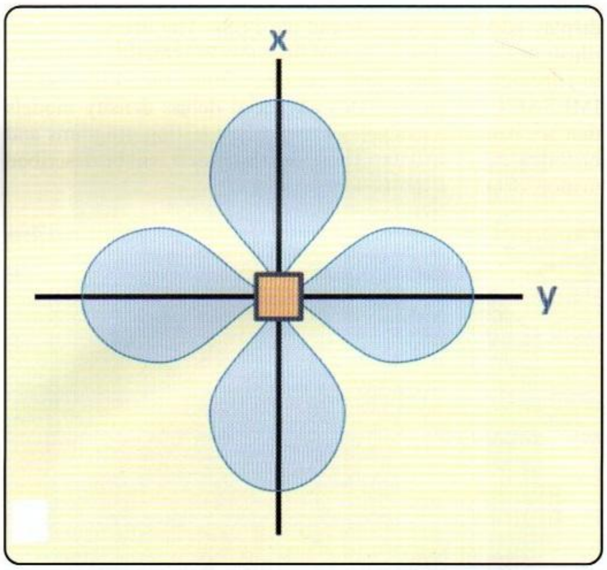


Figure 4 - Wall Debris "Cloverleaf" Pattern (Plan View)

It should be noted that the roof debris is usually modeled as having no azimuthal dependency (i.e., the roof goes up and out in all directions). This is shown in Figure 5, where the tan roof debris lands uniformly at all angles.

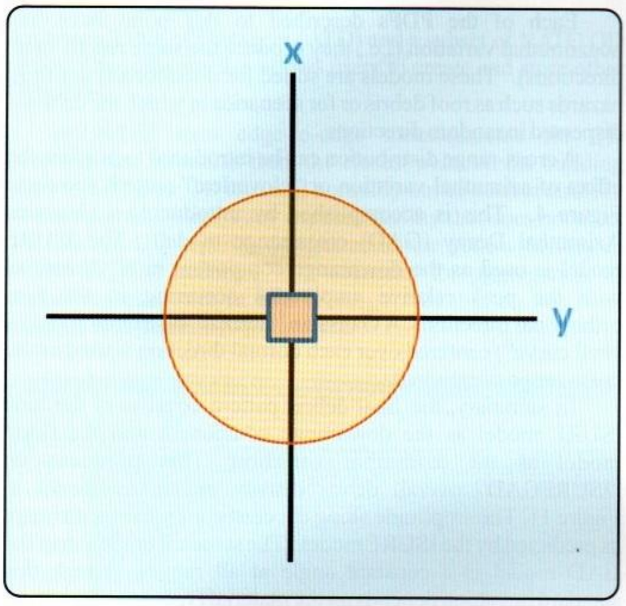


Figure 5 - Roof Debris Uniform Pattern (Plan View)

The wall debris generally travels farther from the donor than the roof debris, so a combined roof/wall debris density pattern typically looks like Figure 6.

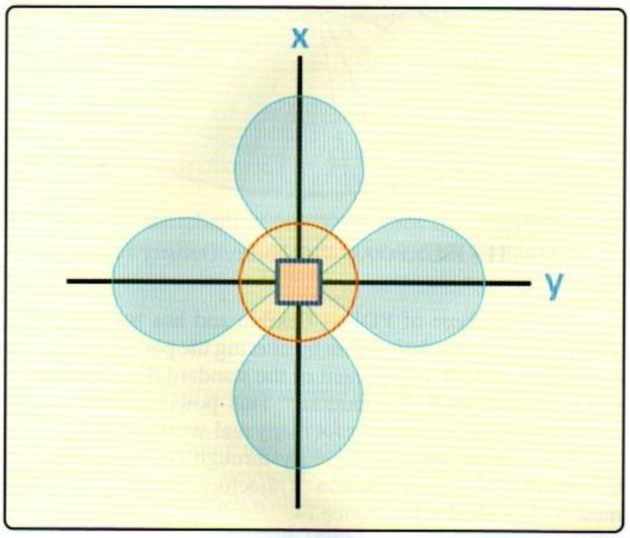


Figure 6 - Combined Debris Pattern (Plan View)

If the charge is not centrally located, or if for any reason the user chooses not to represent the expected azimuthal variation for the wall debris, IMESAFR 2.0 can use an average distance function, similar to what is done in the previously released versions of IMESAFR. This option is shown (overlaying the expected cloverleaf pattern) in Figure 7.

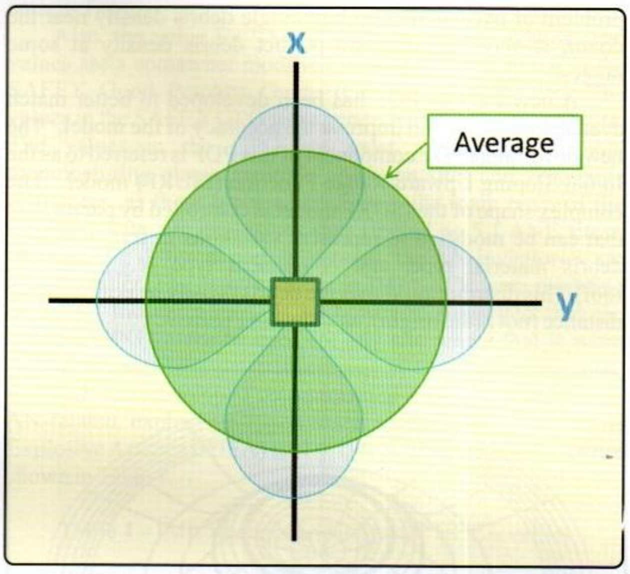


Figure 7 - Alternate Wall Debris Modeling Functions (Plan View)

The debris density models, referred to as Probability Density Functions (PDFs), developed for IMESAFR 2.0 have two principal components as shown in Figure 8. The density as a function of distance from the PES is referred to as the downrange component. The density as a function of azimuthal angle is referred to as the cross-range component. The more simple PDFs have only downrange component and do not vary by azimuth. The BVN "anthill" distribution (shown in Figure 8) has no azimuthal variation and has been used to represent vertical and horizontal debris in the past.

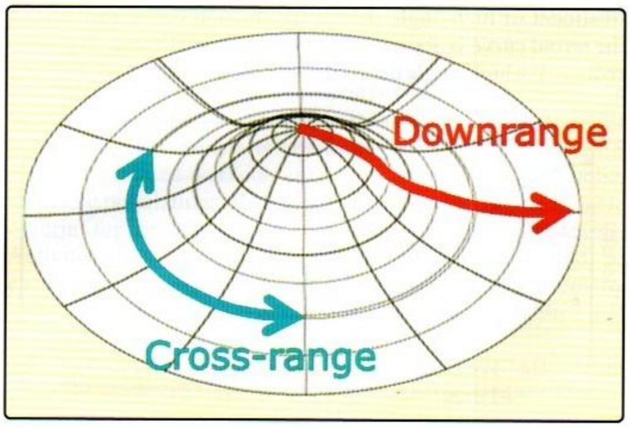


Figure 8 - BVN or "Anthill" Debris Distribution

The BVN PDF has been demonstrated to be conservative at close range [References 10 and 11]. This PDF not only has the problem of over-predicting high-angle debris density near the donor, it may in fact under-predict debris density at some ranges.

A new toroidal PDF has been developed to better match available test data and improve the accuracy of the model. The new downrange PDF component of this PDF is referred to as the Initial Sloping Upward Range Function (ISURF) model. The complex shape of the ISURF model is controlled by parameters that can be modified to represent variations in fragment size, debris material type, and component type (e.g., wall vs. roof). This distribution shows the debris density peaking at some distance (not at the origin), as shown in Figure 9.

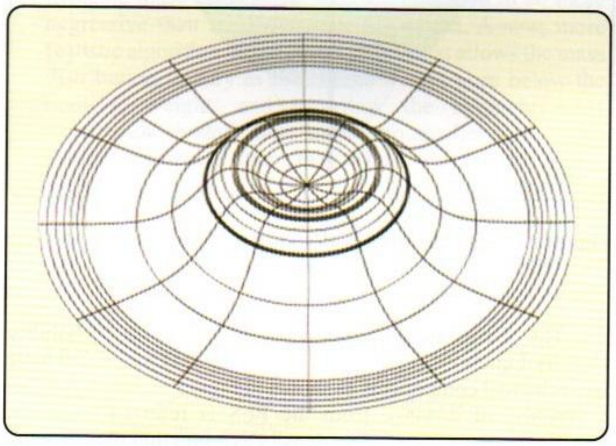


Figure 9 - Toroid Debris PDF Model with the ISURF Downrange Distribution

A comparison of the BVN and toroid distribution options (Figure 10) shows that there is a region where the current treatment of high-angle debris may be non-conservative (i.e., the toroid curve is above the BVN curve), but the toroid greatly reduces the high-angle debris density predictions close-in.

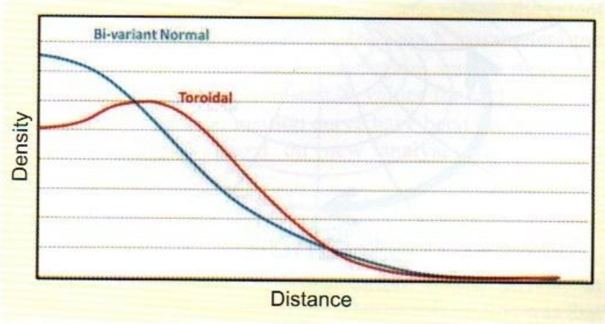


Figure 10 - Cross-Sectional Comparison of BVN and Toroid Debris Distributions

Each of the PDFs described to this point have had noazimuthal variation (i.e., they produce the same results in all directions). These models are suited for directionally-uniform hazards such as roof debris or for scenarios in which the debris is dispersed in random directions.

A cross-range distribution can be introduced to produce the effect of azimuthal variation or "cloverleaf" pattern shown in Figure 4. This is accomplished by introducing a Gaussian Azimuthal Decay (GAD) cross-range model. The ISURF model is used as the downrange component in all directions with the peak relative amplitudes occurring in the four orthogonal directions. A Gaussian "normal" distribution (i.e., a "bell curve") centered over each normal direction is used as the cross-range component.

In summary, the final debris pattern consists of the new ISURF model as the downrange component and the GAD model as the azimuthal variation. This produces an "ISURFGAD" overall debris density model, as shown in Figure 11. The amplitude along the centerline varies with range as predicted by the ISURF model. The standard deviation of the GAD model is a constant angle at all ranges, though this standard deviation depends on the material type.

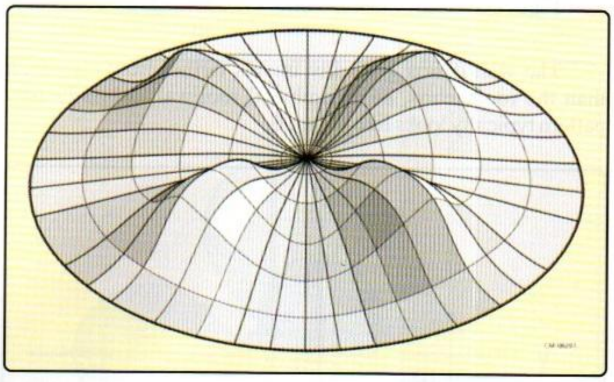


Figure 11 - ISURFGAD Probability Density Function

This new type of PDF is flexible and has been tuned to match test and simulation data by altering the parameters of the downrange ISURF component or the standard deviation of the cross-range normal distribution. This powerful new model provides improved accuracy for many real-world scenarios.

The models for low-angle fly-through debris continue to utilize the Modified Pseudo Trajectory Normal (MPTN) method described in Reference 14.

Quantity-Distance Compliance

IMESAFR 2.0 users can now take QD considerations into account. QD tables have been built into the program and can be visualized in the GIS interface (as shown in Figure 12).

IMESAFR 2.0 currently contains QD criteria from the

American Table of Distances (ATD) and a subset of NATO QD tables. The software also allows users to create and store other QD tables.

IMESAFR uses edge-to-edge measurements for QD purposes, and measures from the closest point on the building (thus meaning the QD arcs will normally not be perfect circles). The software highlights any exposed facility that does not meet the selected QD criteria (designated as the yellow facility in Figure 12).The software also accounts for aggregation of explosives quantities in two or magazines that do not meet magazines separation requirements.

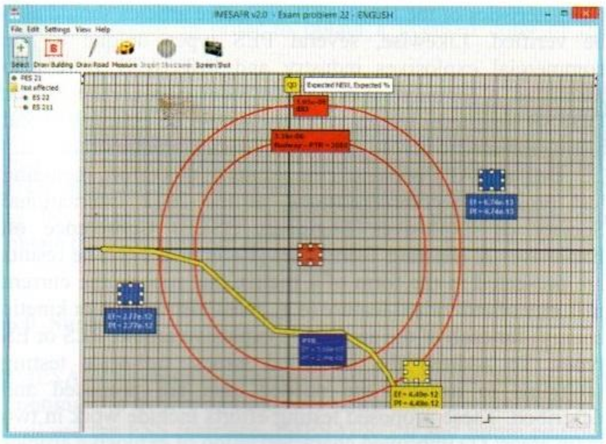


Figure 12 - Example of the QD Display

4.0 Other Support Work

In addition to changes to the software itself, several supplementary efforts have been conducted to advance the state-of-the-art.

P_e Updates

IMESAFR 2.0 incorporates several updates to the Probability of Event options.

The "Bulk loading and unloading" activity type has been split into two subcategories. These include "pump" and "reservoir" options, each with a unique probability of event.

The probability of event values for storage activity types have been updated. The values for different types of storage originated from a mixture of government and commercial sources. This introduced unintended logical inconsistencies when transitioning between compatibility group (CG) options and frequency of handling. The values for "Day magazine storage" and "In-transit storage" were altered to maintain logical consistency for all combinations of CG and storage activity type.

Also, the value for "AN storage" has been updated. The values are a somewhat modified version of those given in the SAFEX Good Practice Guide (GPG) [Reference 18]. The values in the SAFEX GPG were generated using historical data. The values in the GPG are most appropriate for AN manufacturing plants, multiple operation sites and very large AN stores, as these types of sites were the main basis of the historical data. On explosives sites (including 5.1 ANE sites), the risks are different and, in general, the AN inventories are much smaller. The default values in IMESAFR were modified to reflect those realities. It is, however, suggested that the SAFEX GPG values be used for any site where that is more appropriate.

IME has developed recommended values to be used for AN-related explosives types when using the User-Defined Explosive Article (UDEA) tool in IMESAFR. These values are shown in Table 1.

Table 1 - IME Recommendations for UDEA values

Type	Maximum Yield		Expected Yield	
	% Contribution	TNT Equivalency	% Contribution	TNT Equivalency
Packaged 1.5	100% of NEWQD	0.85	70% of NEWQD	0.70
AN Prill	100% of NEWQD	0.42	50% of NEWQD	0.42
1.5* or 5.1 AN Emulsion	100% of NEWQD	0.75	75% of NEWQD	0.68
>92% AN Solution	100% of NEWQD	0.40	25% of NEWQD	0.40

Criteria Development

The IME has developed draft criteria for tolerable risk for use in conjunction with IMESAFR. IME has identified four populations for which tolerable criteria may be set: PES operators, related workers, unrelated workers, and the public. For these populations, IME has proposed quantitative tolerable criteria for broadly acceptable and minimum risk levels. Activities with risk falling between the values would be encouraged to engage in ALARP (as low as reasonably practicable) principles. These values are shown in Table 2 and Figure 13.

Catastrophic event aversion criteria have also been developed. These are shown in Table 3 and Figure 14.

Table 2 - IME Draft Tolerable Risk Criteria

Population	Individual Risk (fatalities/yr)		Societal Risk (fatalities/yr)	
	Max. Broadly Tolerable	De Minimis	Max. Broadly Tolerable	De Minimis
Public	Risks below 1e-6	Risks below 3e-8	Risks below 1e--5	Risks below 3e--7
Unrelated Workers	Risks below 3e-6	Risks below 1e--7	Risks below 3e--5	Risks below 1e--6
Related Workers	Risks below 1e--5	Risks below 3e--7	Risks below 1e--4	Risks below 3e--6
PES Operators	Risks below 3e--5	Risks below 1e-6	Risks below 3e--4	Risks below 1e--5

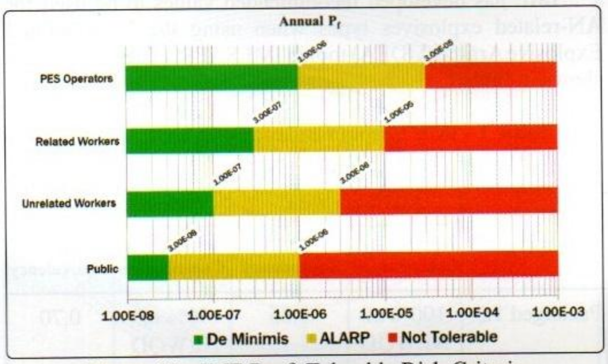


Figure 13 - IME Draft Tolerable Risk Criteria

Table 3 - IME Draft Tolerable Risk Criteria Catastrophic Aversion

Catastrophic Aversion Criteria (fatalities per event)		
Population	**Max. Broadly Tolerable**	**De Minimis**
Public	30	1
Unrelated Workers	35	1
Related Workers	45	5
PES Operators	60	8

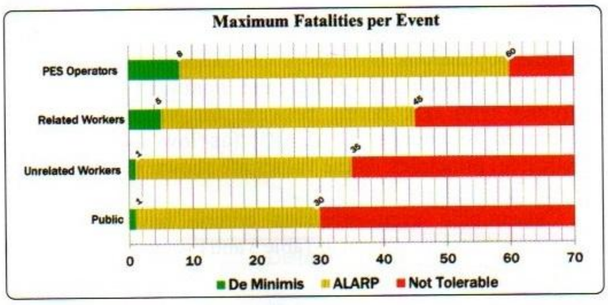


Figure 14 - IME Draft Tolerable Risk Criteria Catastrophic Aversion

Maturity Matrix and Test Program Recommendation

While the consequence algorithms in IMESAFR are considered state-of-the-art, and originally mirrored the algorithms used in SAFER, there is always room for improvement. Therefore, the science and the underlying data behind the software have been assessed for their maturity. This process has identified areas of remaining excess conservatism within the tool that could be improved if data were available. Test data are needed in these areas to continue to remove or reduce such conservatism.

Several explosive articles would appear to benefit from a more realistic characterization of their air blast and fragmentation characteristics. The sympathetic detonation characteristics of the IMESAFR explosive articles should also be verified. Likewise, several PES types unique to the commercial explosives industry and IMESAFR were also identified. A commercial explosives industry equivalent of the DDESB long-term testing program should be established and testing initiated to investigate these industry-unique structures.

IME and APT presented the results of this effort, including test program recommendations, at the 2012 International Society of Explosives Engineers (ISEE) Conference on Explosives & Blasting Techniques [Reference 17]. The results are presented in the form of a matrix that reports the current maturity of individual feature (e.g., mass distribution or kinetic energy) for each of the applicable explosive article, PES or ES types. To address the identified issues, full-scale testing programs to provide the needed data are proposed and described. These proposed testing efforts include work in two main areas: (1) improved characterization of explosive articles that are unique to the IMESAFR software (i.e., not in SAFER) and (2) more refined modeling of the Potential Explosion Site (PES) types that are unique to IMESAFR, particularly small metal structures. The goals of each of these test programs is discussed in detail, as well as the requirements involved with conducting the actual tests.

IME has proposed a series of tests for the coming years. The first test would be an elevated Ammonium Nitrate (AN) and/or Ammonium Nitrate Emulsion (ANE) bin. This test has been budgeted for 2016. The second test series is for perforating guns and has been budgeted for 2017. The final planned test is for US Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) type magazines. This test or test series is planned for 2018.

Furthermore, users of IMESAFR are encouraged to suggest aspects of the program that appear to be unduly conservative and work with IME and APT to design a test program to generate the necessary data.

TP-14 Equivalent

In the past, the technical reference for IMESAFR has been TP-14 [Reference 13].With minor interpretive insight, TP-14 has adequately served this purpose since the algorithms were so similar and differences have been reported in the open literature.

However, to document the new features and advanced algorithms as well as to provide additional transparency, IME and APT have developed an equivalent to TP-14 for IMESAFR 2.0.This document eliminates the need for any interpretation and consolidates all technical background for the IMESAFR 2.0 algorithms. The document is titled "IMESAFR Technical Manual," and will be formally published by IME in early 2015.

5.0 Release Information

IMESAFR 2.0 was officially released in February of 2013and is commercially available for use internationally. As with previous versions of the software, IME normally requires that users be trained in order to obtain a licensed copy of the software.

IMESAFR has a NLR designation (not requiring license) under US Export Administration Regulations (EAR) if shipped to countries other than those the Department of Commerce has listed as restricted(currently Cuba, Iran, Sudan, and Syria). Users from outside the US have the same access to IMESAFR as they do to other items in IME's Safety Library, or they can obtain the software from APT.

6.0 Summary

IMESAFR has been commercially available since 2007 and has continued to evolve and improve since then. Because SAFER will use the ESS interface, IMESAFR 2.0 and future editions will use a different interface. IMESAFR 2.0 has been developed and was released in February 2013.

IMESAFR 2.0 includes many new features and incorporates a completely redesigned GIS-based GUI and debris density model. This new interface and new advanced debris algorithms allow the user much more control over the realistic treatment of real-world scenarios, and the results can be visualized in new and powerful ways. Users can also set-up cases and review results in metric units.

IME and APT have conducted additional work to support the release of Version 2.0 (as described in Section 5), and are pleased to be able to include QD compliance features in the new software.

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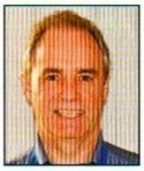
The use of IMESAFR in the Explosives Industry : Three Case Studies



Bill Evans
Chairman, IMESAFR Subcommittee (Institute of Makers of Explosives)

1.0 Introduction

1.1 Purpose

This paper will provide three case studies where IMESAFR was used by an explosives company to get exemptions from quantity distance (Q/D) or other related regulations. The examples are all from the same explosives company and are all from Canada. The explosives company is a large, global supplier. The examples are all from Canada because, to date, Canadian regulators have been by far the most open in considering risk based assessments, i.e. Quantitative Risk Analysis (QRA), to provide a single case exemption from, generally, Q/D regulations.

1.2 Background/History

There are two significant QRA tools that were developed in the United States, Safety Assessment for Explosives Risk (SAFER) and Institute of Makers of Explosives Safety Analysis for Risk (IMESAFR). The software package for SAFER was developed by APT Research, Inc.(APT) for the U.S.Department of Defense (DoD) in recognition that Q/D does not always provide the 'best' answers for siting explosives inventories and that a risk based approach provides significantly more flexibility. SAFER is a fast running risk calculator for explosives 'events' (i.e. generally accidental explosions but can be used for intentionally initiated explosives inventories). Risk implies both frequency and consequence terms. In general within IMESAFR, the frequency term is based on historical data while the real capability of SAFER/IMESAFR is to calculate a realistic consequence for any such event. The algorithms in SAFER are based on large scale test data carried out by the U.S. DoD and others. The original algorithms have evolved as newer test data has become available resulting in the release of several significant upgrades to both SAFER and IMESAFR.

The Institute of Makers of Explosives (IME) recognized that a commercial explosives industry equivalent to SAFER could have huge value to that industry. The IME contracted APT to develop IMESAFR. The IME owes a huge debt of gratitude to the U.S. DoD who allowed APT to use the existing SAFER algorithms, without which IMESAFR would probably either not have been developed or would have been long delayed as the cost of starting from scratch might well have been prohibitive for an industry association such as the IME. IMESAFR first became available in 2007 and has gone through three iterations since: the first two being relatively small step changes followed by a 'quantum jump' to IMESAFR 2. Interestingly, the U.S. DoD now sees IMESAFR as being more advanced than SAFER and will be using some aspects of IMESAFR 2 in the next version of SAFER.

1.3 Q/D versus IMESAFR Based QRA

The main attraction of Q/D is the sheer simplicity: if one has quantity X then one needs to be at distance Y to 'be safe'. And therein lies the main flaw of Q/D. A person standing 10 cm outside the Q/D arc is not absolutely safe and does not become unacceptably at risk if he takes a small step forward. Q/D is simply too simplistic as there are a plethora of other factors that matter hugely in the actual risk. Q/D takes no or only marginal account of the following factors (not a comprehensive list):

- Type of explosives (e.g. pentolite vs ANFO)
- Activity type
- Construction of PES (Potential Explosion Site), many factors
- Construction of ES (Exposed Site), many factors
- Angle from PES to ES (has a huge effect on any roughly rectangular PES)
- Time of PES operation
- Times of ES occupation

IMESAFR is capable of taking these factors into account and calculating the actual risk and consequences at any distance and angle, which can matter as much as the distance, from every PES to every ES. If the main 'job' of Q/D is to protect the public from accidental explosions, then the case that IMESAFR does this better is very strong indeed.

1.4 Industry Uses in Canada

In Canada, there are four areas where the Explosives Regulatory Division (ERD), part of Natural Resources Canada (NRCan), will generally consider an IMESAFR based QRA for an exemption from Q/D or other regulations:

- Highway twinning or other improvement jobs where bulk explosives are preferred
- Other construction jobs where bulk explosives are preferred
- Temporary sites
- Encroachment on existing sites

It is possible that ERD will also consider an IMESAFR based QRA for a change on an existing fixed plant. At least one such issue is currently under discussion with ERD. Three examples are given in this paper, covering the first, second and last of the four areas listed above. No example for 'Temporary Sites' is given because it is generally just a simplified version of the first application.

2.0 Examples of Use within the Commercial Explosives Industry

2.1 Highway Twinning

This is a major construction activity in Canada as the growing population and/or road transportation necessitates the upgrading of old single lane 'highways' into modern divided highways. Canada is a very large country with a relatively small population (10% larger and 90% smaller than the United States, respectively). Travel distances can therefore be very large indeed and divided highways provide obvious benefits/efficiencies in both individual travel and commercial transportation. Canada is also a country where there is a very thin layer of soil over very hard rock, especially in Eastern Canada (the Canadian Shield). The East also has 'significant topography', unlike the Prairies of Central/Western Canada. All of this means that building of new roads/twinning of old roads will inevitably require the application of significant amounts of explosives.

Bulk products offer obvious benefits to contractors in the speed and efficiency (plus cost effectiveness) of the construction project. All bulk products in Canada are classified as Class 1.5 explosives, which adds a significant degree of difficulty to the explosives subcontractor. This is because a mobile process unit (MPU), a vehicle for the loading of bulk explosives, is treated as an explosives inventory requiring full Q/D. This is clearly impossible when one is working right beside an existing road that will be open for the entire duration of the project. The Government of Canada recognized this issue, that it imposes a significant burden on the contractors and that the actual risk of a limited bulk loading operation is very small. Therefore ERD will allow the use of bulk explosives if the explosives contractor can demonstrate that there is an acceptable level of risk to the public from this operation.

Before the advent of IMESAFR, calculating the risk was very difficult. It was easy enough to come up with a defensible frequency for bulk truck explosions based either on historical data (extremely rare) or through a Fault Tree or other QRA methodology. The explosives company in this case had earlier carried out a very detailed risk analysis to determine the frequency of bulk truck explosions, led by a respected external consultant and including a future Senior Inspector of Explosives for ERD. The number generated is smaller than the default value within IMESAFR, largely due to the enhanced safety/interlock system used on all MPU product pumps, has been accepted by ERD and is used in all such QRAs. But very conservative assumptions had to be made on consequences and this led to some reasonable bulk loading opportunities not being undertaken. Fortunately, ERD personnel have been on the IMESAFR Development Team since the start, providing significant credibility/acceptance of the program. ERD therefore accepts IMESAFR based QRAs on this type of project.

ERD requires the following inputs:

- MPU I.D. and capacity (the QRA must assume full capacity)
- Duration of project
- Actual hours on bench/loading
- Average traffic volumes for all roads 'in range' (both vehicles and estimated occupants)
- All inhabited buildings within range along the entire project.

Notably, IMESAFR requires all the same inputs (some in slightly different formats).

The example project has been selected because it offers several interesting points.

The highway twinning was on the main road between Montreal and Gatineau (formerly Hull, just across the river from Ottawa). At one end of the specific project that was covered by this QRA was a small village, most of the project was through wooded, very sparsely populated country and the project ended outside a sizable community.

ERD has a published Individual Risk Target of 1E-06, which is the most common such target globally. They also have an unpublished (and at that point, not fully defined) catastrophic risk aversion target. The first target simply means that the member of public most at risk (normally closest, but not always, as IMESAFR can demonstrate) has a one in a million chance of dying from an accidental explosion of the MMU on this job. Traffic is treated differently as the risk is very transient and very small except close into a significant explosion.

Therefore the analysis was divided into three parts:

- The first part was the largely uninhabited middle portion of the project. The worst point along the entire length, in this case where three inhabited buildings were within range (D7 in Canada, Public Works B (PWB) in the more common nomenclature for NATO based Q/D systems), two just barely. Note that this is equivalent to the ATD (American Table of Distances) IBD (Inter Building Distance), but the ATD is less conservative. IMESAFR was used to calculate the risk (the internal event frequency with IMESAFR calculated consequences) to the residents and vehicle traffic. The individual risk was more than an order of magnitude below the ERD target and the worst case event generated well under 1 fatality (on average). Doing the worst case calculation is the easiest way to handle projects that can cover tens of kilometers as clearly meeting the risk criteria at the worst point means an even easier pass for the rest of the project. ERD accepted this part of the proposal.
- The first cut at the near end of the project (the village end) showed that although the individual risk met the target, the Pf|e (Probability of Fatality given the Event) was uncomfortably high and applied to most of the village. So while this was a nominal pass, it was not a comfortable one. Following discussions with ERD, the company agreed to use a different MPU (smaller capacity) on this portion of the contract. This did not reduce the frequency portion of the risk, but did reduce the consequences significantly. ERD was happy with/accepted this proposal.
- The company had no intention of proposing the use of bulk explosives at the town end of the project. While calculations showed that the individual risk target was met fairly easily, this was largely due to the previously negotiated low event frequency used in the analysis. Should the event happen, there would likely have been a large number of fatalities. Although it was not known what ERD's catastrophic risk aversion target was (see the final case study), the company was well aware of its existence from discussions with ERD. The determining factor was that there was a vulnerable facility within range at the very end of the project. Vulnerable facilities are defined in some jurisdictions by building type (e.g. multi-story buildings with lots of glass), by occupants (e.g. students, elderly, hospital patients) in other jurisdictions. Canada uses either/both to define a vulnerable facility and has made it clear that no Q/D exemptions will be granted in these cases. So the contractor had been told from the start that only packaged products would be used in this area.

The QRA covering the three different loading methods over the project was presented to and accepted by ERD. Without IMESAFR, more conservative consequence assumptions would have been made and packaged explosives would have been used at both ends of the project and to greater distances from both the village and town. This would have added both costs and time to the project. The difference between using bulk and packaged explosives on this type of project can be tens of thousands of dollars and the addition of several days to the timeline.

2.2 *Site Encroachment*

The site in this example is in Western Canada and has been in existence for many decades. It is a major magazine site for Western Canada and also has two small manufacturing plants. As was common in the past, the surrounding area had zoning restrictions to prevent encroachment within the Q/D circles around the various explosives inventories on the site. Those zoning restrictions were removed (without consultation) and a waste management company was given permission to use the land on one side of the site as a landfill area. The waste management company also decided to put up a large building to be used as an environmental education centre, meaning that busloads of students could be present in that building. The building was outside the normal D7/PWB arc but because of its construction was considered to be a vulnerable facility (D8 or Vulnerable Facility arc).

The company did a site Q/D review based on these new constraints and the analysis showed that the site inventory would need to be reduced by 185,000 kg to meet full Q/D compliance. This would have necessitated finding another site somewhere relatively nearby to build some new magazines as the Western Canadian business would have run into major logistical issues with that great a loss of capacity at a main storage and distribution site. After discussions with ERD, it was agreed that because there would only be intermittent occupation of the centre by significant numbers of people, a risk based exemption from the full Q/D requirement (D8 or two times D7) might be granted. It was also agreed that the workers in the landfill area would also have only intermittent exposure and could also be treated on a risk rather than Q/D basis.

Of the explosives inventories on site, seven affected the landfill area but only three affected the centre. The two populations (workers/landfill and visitors/centre) were treated separately in the QRA (this is automatic in IMESAFR) because they had very different exposures and also different risk targets. Because of the relatively low number of landfill workers exposed, only individual risk came into play here whereas the individual risk was very low at the Education Centre so only the catastrophic risk aversion criterion was important.

As is generally best (certainly easiest), the worst case was studied first. For the landfill workers, that was the maximum number of workers possible (10; 5 in vehicles, 5 on foot), present for the entire shift with the total risk being calculated as seven times (because of exposure to seven inventories) the single worst exposure. The average risk of these workers was treated by calculating the risk (on foot and in vehicles) at the closest exposure point, the furthest exposure point (the D7 boundary) and halfway in between, then averaging those risks and applying them to all the workers. This is a valid approach because any of the workers could be anywhere in that area at any time and because of the work program in place, clusters of workers was very unlikely. As it turned out, even at the closest point, the individual risk was acceptable, i.e. below 1E-06 even when multiplied by 7, and the risk at the far end was about two orders of magnitude lower. Therefore this was an easy pass on individual risk for the worst case and the worst event resulted in less than one fatality.

The same approach was taken for the Education Centre, where the calculations were done for the closest inventory (all three inventories were the same, so the closest would generate the highest risk) with that risk multiplied by three to account for the three PES's. The individual risk was very low, as would certainly be expected out near the D8/Vulnerable Facility arc. The Pf|e was used to calculate the catastrophic risk for the worst event. This was also under one fatality, even with a large number of people in the Centre (the maximum expected). Glass breakage was the major hazard and could be further reduced by changing glass type (a 'what if' that IMESAFR can calculate). This was discussed with ERD, the Provincial Government and the waste management company and it was agreed that this change would be made (the advantage of doing the analysis pre-construction).

The IMESAFR based QRA was provided to ERD who agreed that no inventory reduction was necessary on the site as the study had demonstrated that the risk was adequately low/met Canadian standards.

2.3 Construction Job

This case study is for a large hydro electric project in northern Manitoba. Explosives were necessary to excavate the new pathway to the generator turbines. The schedule was very tight which meant that bulk explosives had to be used. This led to the same issue as for the highway twinning project, i.e. full Q/D is nominally required around the bulk truck. Q/D is not required for people whose livelihood directly includes the use of explosives, e.g. MPU operators and blasting crew. However, the tightness of the schedule meant that the contractor wished to continue other excavation operations while the MPU was on the bench/loading holes. This would only be allowed by ERD if the risk could be demonstrated to be acceptably low.

In this case study, the site was very remote from any inhabited buildings and the only road was the access road to the site. Therefore only contractor personnel needed to be considered. There could be up to 100 contractor personnel on the site, divided between three temporary offices (trailers) and the area being excavated. The latter area was by far the most populous during the day.

As normal, the analysis started with the worst case, i.e. a full load of product at the point closest to the three offices. The analysis showed that both the individual risk and worst case event easily passed the standard risk criteria. The workers in the excavation area covered a significant area at significantly different distances to the MPU. The treatment was the same as for the workers in the landfill case where the risk nearest, furthest and middle were averaged. While the individual risk of the workers in the excavation area was adequately low due to the very low event frequency, the worst possible event would have killed more than forty workers. ERD, which did not have a published standard for the catastrophic risk aversion number, stated that this was too high.

Discussions were held with the contractor and they agreed to two changes: the active work area would be further away from the loading operation and only in already partially excavated areas. Therefore these workers would essentially be in a trench with no direct line of sight to the MPU and could be treated as barricaded (ERD agreed to this treatment). The worst case fatality rate did come down when IMESAFR was rerun incorporating these changes but was still uncomfortably over 30.ERD again deemed this to be too high and another set of discussions was held with the contractor. They now agreed to reduce the number of workers in the excavation area during loading operations to those necessary to carry out the most time critical operations. IMESAFR was rerun with these changes and now the worst case event resulted in about 20 fatalities. ERD deemed this to be acceptable.

3.0 Conclusions

An IMESAFR based QRA is clearly more complicated and complex than just running simple Q/D. Yet simple Q/D would not have allowed two out of three of the above case studies and would have resulted in a huge inventory reduction in the third. This is why QRA is a clear win for industry. However, the regulator must be treated as your customer for this, not your adversary. Industry will always be more comfortable with 'acceptable risk' than a regulator and that is perfectly reasonable given the different remits.

The above case studies show that these exercises were often an iterative process with open consultation with the regulator. It is also a great help when the regulator has official risk targets to both industry and the regulator. This makes it a yes/no decision again. But instead of 'you have X kgs of explosive, are you Y meters from this building', it becomes 'you have x kgs of explosive in this type of building, of this construction, with this type of activity and at this orientation, etc; is the risk at this ES with this construction, with this percent glass of this type occupied by this many people this percent of the time, etc. Acceptably low?'

Effect of Blasthole Diameter on Explosives Energy Release Characteristics

Dr. A.K. Jha
Senior Manager, Blasting Cell
Central Mine Planning and Design Institute Limited, Ranchi

Dr. G.R. Adhikari
Professor, Department of Mining Engineering,
GEC, Goa

ABSTRACT

Evaluating and selecting a blasthole drill for surface mines is a strategic and technical proposition as the success of an entire mining project or operation hinges on the ability of the drill to produce the required production, proper fragmentation for achieving mine productivity and economics. It is therefore important to select a proper blasthole diameter for any mining project. In this study, explosives energy release rate is considered as one of the parameters for selection of blasthole diameter for opencast mines and the energy release characteristics are directly linked to confined (in-the-hole) velocity of detonation (VOD) of explosives. Field measurements for in-the-hole VODs of large diameter, non-permitted bulk emulsion product having chemical gassing were systematically conducted at three large opencast mines for different diameters. This study strongly indicates that an increase in the blasthole drill diameter increases the confined (in-the-hole) velocity of detonation (VOD), affecting the energy release characteristics of explosives as a function of drill diameter. The minimum diameter for steady state detonation velocity for large diameter non-permitted and bulk emulsion product having chemical gassing may be approximated as 84 mm. For chemically gassed emulsion explosives, it is found that the maximum explosive energy release in Indian coal mines is achieved at 200-250 mm. Therefore, the mine planner and operators may restrict the blasthole diameter to 200-250 mm for shovel dumper combination, particularly while operating in close vicinity of the habitants in order to achieve good fragmentation as well as to minimise the environmental impacts of blasting. Larger diameter blastholes may be considered in dragline benches only.

1.0 Introduction

The selection of blasthole drill has to done judiciously by mine planners with due regard to technical, planning and operational issues. Selection of optimal drill for any mine should be considered on the basis of rock mass characteristics, degree of desired fragmentation, environmental constraints, regulatory guidelines and scale of operation. The optimal diameter and bench height considering optimization decisions comprising planning parameters and operational parameters for Indian coal mine will govern the overall blasting, mine productivity and economics. There is a need to select an appropriate drill diameter as it has an important cost-benefit ramification. Blasthole diameter in opencast coal mines varies from 100 mm (mid-sized drills) to 406 mm (large rotary drills) with weight on bit varying from 11300 kg to 56700 kg. The current trend of mine operators is to select larger drills as well as multi pass mast drilling methodology (drill depth up to 80-85 m) over single pass mast drilling methodology (drill depth up to 20-25 m) to gain in terms of drilling time and drilling volume. Table 1 shows the techno-economic considerations to be used by the mine planner and operators for selecting a blasthole drill. The large diameter drills have asymptotically higher price as compared to smaller diameter to a such extent that 381 mm drill is 10 times (approx.) costlier than 250-270 mm drill.

Table 1 - Characteristics of Various Blasthole Drills for Opencast Projects

Diameter of the Drill (mm)	Bench height (m)	Life (years)	Life (hours)	Weight on Bit (1000* kg)	Feed Speed (m/s)	Capital Cost (Rs. in Crores)
100-115	10-12	7	8000	11 - 13	0.4	0.55
150-160	13-18	9	12000	20	0.4	1.20
160-200	16-22	9	12000	24	0.6	1.20
250-270	22-28	9	20000	30 - 35	0.6	3.30
311	28-35	12	30000	35 - 40	0.6-0.8	18.50
381	35-40	12	30000	55 - 58	0.6-0.8	33.50

Under the 'Mine-to-Mill' concept, the "blasting subsystem" plays a very pivotal role to improve mine productivity and efficiency of any opencast mine. The blasting subsystem affects various other subsystems viz. loading, hauling, transportation and milling subsystem to a great extent. Of late, mine operators prefer to go for large size blasts with large drill diameter to meet the production demand. On the contrary, large diameter drills are not suitable for opencast mines which are operating near the dwellings and villages, where explosives charge per delay is to be restricted in order to minimize ground vibration, air over pressure, fly rock, damage to the structures and other environmental nuisances. Under such circumstances, the use of large size blast drills needs multiple decks resulting into adverse explosive loading configuration from uniformly distributed charge mass to concentrated charge mass. The paper discusses the impact of energy release characteristics of explosives as a function of drill diameter using in-the-hole velocity of detonation data. It also discusses the methods adopted to determine critical diameter as well as the diameter for attaining maximum energy release rate in order to recommend suitable blasthole diameter for opencast coal mines.

2.0 Selection of Blasthole Diameter

The drill diameter for any opencast mine depends on the following key parameters:

- Required/ targeted production
- Terrain or profile to be negotiated for coal or mineral exploitation
- Site-specific material characteristics to be handled
- Type and size of excavating and hauling equipment
- Proximity to vibration-sensitive areas.
- Bench or "lift" height in compliance to the regulatory provisions
- Availability of type of explosives at mine site

As the bench height is decided considering production requirements, scale of operation, economics and regulatory conditions, the drill diameter should be also be selected considering the desired fragment size, type of explosives and accessories to be used during blasting, environmental as well as regulatory issues prevailing in vicinity of mine, the thumb rules available in the literature for blasthole diameter are in terms of bench height. Table 2 shows the relations between these two parameters suggested by various investigators.

Table 2 - Proposed Relations between Blasthole Diameter (d) and Bench Height (H)

Sl. No.	Name of Researcher	Proposed relation
1	Konya and Walter , 1990	$d = 0.016 * H$
2	Atlas Powder Company, 1987	$d \approx 0.0083 * H$
3	Roxborough and Sen, 1986	$d = (0.005 \text{ and } 0.0125) * H$
4	Tamrock, 1987 -88	$d = (0.005 \text{ to } 0.01) * H$
5	Adhikari , 1999	$d_{min} = 10H$ $d_{max} = 16.66H + 50$ where d_{min} = minimum blasthole diameter, mm d_{max} = maximum blasthole diameter, mm

For a given bench height, the hole diameter, estimated diameter from the different thumb rules, varies but within the limited of diameters. Hence, criteria for maximum and minimum blasthole diameter were suggested (Adhikari, 1999). The maximum blasthole diameter is restricted by:

1. Maximum acceptable size of fragments: If the blasthole diameter is too large, increased burden and spacing will lead to coarse fragmentation and the costs of loading and crushing will be high. Thus, fragmentation is a determining factor that restricts the maximum blasthole diameter.
2. Environmental constraints: When blasting operations are carried out near populated areas, it is necessary to restrict the blasthole diameter to minimise the risk of ground vibration, fly rock and air overpressure.
3. Length to diameter ratio of the charge: For a certain bench height, an excessively large blasthole diameter (d) makes the charge length (l) very short. The explosive charge will be poorly distributed and hence will not break the rock satisfactorily. Practically, it is established that $l/d \geq 20$.
4. Powder factor: In mines where the blasthole is large for the given bench height, powder factor for the same rock mass conditions has to be increased to compensate the poor distribution of explosive charge in the rock mass, although powder factor can be kept minimum by resorting to conventional decking or air decking.
5. Blasting damage to rock slopes: As the blasting damage to rock slopes and benches is higher with larger diameter, the maximum blasthole diameter is restricted by this factor.

Similarly, the minimum blasthole diameter is restricted by:

1. Critical diameter of the charge: The minimum blasthole diameter must be greater than the critical diameter of the explosive. Since blasthole diameters used in surface mines are usually larger than 100 mm which are greater than the critical diameter of modern explosives and blasting agents, this is not a problem in most surface mines.
2. Drilling and initiation costs: If the blasthole diameter is small, the costs of drilling, priming and initiation are high due to increased number of holes. This is the limiting condition for the minimum blasthole diameter.
3. Length to diameter ratio of the charge: If the blasthole diameter (d) is too small, the charge length (l) will be too long and sufficient room will not be left for stemming. Practically, there is no advantage if $l/d > 70$.
4. Scale of operation: Blasthole diameter should be large enough to meet the required volume of blasted rock and to reduce the frequency of blasts.

The practical challenges in selection of optimal blasthole drill diameter are as follows:

1. In coal mines, the thickness of coal seam or parting restricts the bench height. Under such scenarios, the blasthole drill may not be compatible to the bench height.
2. In some of the lignite, sandstone mines where excessive

cohesion of the rock mass creates problem in flushing of the holes during drilling operation. In such conditions, the blasthole diameter is kept more than minimum diameter to clear the gumming. In some copper or iron ore mines, the blasthole diameter and bench height is not compatible due to frequent jamming of the holes.

3. In construction blasting, where the volume of rock mass to be blasted is very limited and nature of job is short termed, low diameter blastholes are selected by the operators due to high price of larger sized drills.
4. In some case, the mine regulators impose the condition of restricting the explosives charge per delay which forces the mine operator to reduce the bench height. As the blasthole drills are procured for a fixed life, it becomes a constraining factor on operators to use the sub-optimal blasthole drills under reduced bench height scenarios.
5. In coal mines, where run off mine is fed to the washery or in metal mines where extracted mineral is fed to the crusher, the feed size restrictions of the crusher compels the operator to use smaller size drills to ensure well fragmented muck.

3.0 Research Methodology

In this study, explosives energy release rate was considered as one of the parameters for selection of blasthole diameter for opencast mines and the energy release characteristics are directly linked to confined (in-the-hole) velocity of detonation (VOD) of explosives. The VOD of explosives is defined as the rate at which the detonation wave front travels through an explosives column. It remains fairly constant for a given explosives matrix but varies from one explosives matrix to another depending primarily on the composition, particle size, density, charge diameter and degree of energy release rate characteristics (Sun et al, 2001). The in-the-hole VOD of an industrial explosives is dependent on explosives charge diameter and borehole diameter (Jimeno et al, 1995). The diameter versus VOD curve provides a fundamental guide to the rate of energy conversion and energy release within the detonation head on the interaction of explosives with the confining medium.

The minimum diameter of the drill hole is decided by the concept of 'Critical diameter' of an explosive formulation. The critical diameter is the minimum diameter of a specific explosive in which the explosive will detonate reliably. The steady state detonation after initiation is required to be obtained as quickly as possible for providing desired detonation pressure to the rock mass. The quicker the steady state of detonation is achieved inside the blasthole, the better would be the blast performance.

In-the-hole VOD of large diameter, non-permitted bulk emulsion having chemical gassing explosives was measured at three opencast mines by deploying Multi-channel Data acquisition system named DataTrap-II manufactured by M/s MREL, Canada. It essentially measures a change in the resistance of the VOD probe cable suspended in the charged hole during detonation. As the detonation wave travels along the explosives column, it consumes the probe which decreases the electrical resistance in linear manner and is measured by DataTrap-II.

The field trials were carried out in Umrer project of Western Coalfields Limited, Kusmunda project of South Eastern Coalfields Limited and Mine 1 & II of Neyveli Lignite Corporation (Coal S&T Report 2010). The brief descriptions of all the locales are mentioned below.

3.1 Umrer Project

Umrer project of Western Coalfields Limited is located in the Umrer Coalfields. It is well connected by roads. The Nagpur railway station is about 45 km from the project. Three coal seams viz. seam IV, seam III and seam II are mainly exposed in the mine. The mine is producing about 3.1 Mt of coal and removal of overburden is about 11.12 million cubic meters. The average stripping ratio of the mine is 2.7 m^3 per tonne coal produced. The dip of the mine is 1 in 10. An overview of the Umrer project is shown in Figure 1.

Figure 1 - Umrer Project

3.2 Kusmunda Project

Kusmunda project is located on the western bank of Hasdeo River in the central part of Korba Coalfields in the district of Korba in the State of Chhattisgarh. The project is well connected to Korba and Bilaspur by rail and road. The nearest railway station is Gevra Road of Champa-Gevra branch line of South Eastern Railway. The Kusmunda project is having a flat terrain with minor undulations. The area of the project is covered generally by soil/sub-soil. The upper Kusmunda seam incrops below a cover of 6-31 m in an elliptical fashion and overlies lower Kusmunda seam after sandstone parting of 65 to 75 m. The area constitutes a doubly plunging anticlinal trend. The lower Kusmunda seam is composite in Western part of the property but the same splits into two sections, namely Lower Kusmunda (top split) and Lower Kusmunda (bottom split) Eastwards. One oblique set of faults strike across the anticlinal axis, while the other set of faults appear to strike parallel to the anticlinal axis. The seam generally has a dip ranging from 50^0 to 100^0 (1 in 5.6 to

1 in 11.5) and the overall grade of coal is Grade 'F'. The mine was producing about 10 Mt of coal per annum and total overburden handled annually is about 11.6 million cubic meters. An overview of the operative benches is shown in Figure 2.

Figure 2 - Kusmunda Project

3.3 Neyveli opencast mines

Mine-I & II of Neyveli Lignite Corporation Limited (NLC) is situated in the Cuddalore district of Tamil Nadu State. NLC is endowed with a proven existence of 3300 million tonnes of lignite in an area of 480 sq. km. Mine I is spread over an area of 26.69 sq. km with a reserve of 365 million tonnes of lignite. The mine has production capacity of 10.5 million tonnes of lignite per annum. Mine-I feeds lignite to Thermal Power Station-I (600 MW) and Thermal Power Station-I Expansion (420 MW). German excavation technology in opencast mining using Bucket Wheel Excavators, Conveyors and Spreaders was used in the mine for the first time in the country. The overburden to lignite ratio in this mine is 5.5 m^3 to one tonne. Mine-II is spread over an area of 26 sq. km with a reserve of 390 million tonnes of lignite. The mine has production capacity of 10.5 million tonnes of lignite per annum. Mine-II feeds lignite to Thermal Power Station-II (1470 MW). German excavation technology in opencast mining using Bucket Wheel Excavators, Conveyors and Spreaders was used in the mine. An overview of the Mine-II is shown in Figure 3.

Figure 3 - NLC Project

4.0 Results

The measured VODs of explosives at the selected mines for different blasthole diameters but for identical explosives composition of same particle size, density, viscosity and loaded into blastholes with the same degree of energy release characteristics are given in Tables 3, 4 and 5 (Coal S&T Report 2010).

Table 3 - Measured in-the-hole VOD of Explosives at Different Borehole Diameters at Umrer Project

Sl. No.	Hole diameter (mm)	In-the-hole VOD (m/s)	Average VOD
1	160	4480	4544 m/s in 160 mm diameter
2	160	4494	
3	160	4565	
4	160	4638	
5	250	4778	4799 m/s in 250 mm diameter
6	250	4820	
7	270	4835	5070 m/s in 270 mm diameter
8	270	4840	
9	270	4911	
10	270	5019	
11	270	5049	
12	270	5148	
13	270	5155	
14	270	5337	
15	270	5339	

Table 4 - Measured in-the-hole VOD of Explosives at Different Borehole Diameters at Kusmunda Project

Sl. No.	Hole Diameter (mm)	In-the-hole VOD (m/s)	Average VOD
1	160	4498	4570 m/s in 160 mm diameter
2	160	4503	
3	160	4515	
4	160	4538	
5	160	4599	
6	160	4642	
7	160	4694	
8	260	4778	5013 m/s in 260 mm diameter
9	260	4819	
10	260	4854	
11	260	5058	
12	260	5069	
13	260	5128	
14	260	5131	
15	260	5138	
16	260	5140	

Table 5 - Measured in-the-hole VOD of Explosives at Different Borehole Diameters at Mine-I & II

Sl. No.	Hole diameter (mm)	In-the-hole VOD (m/s)	Average VOD
1	100	3467	
2	100	3501	
3	100	3528	
4	100	3594	
5	100	4288	4200 m/s in 100 mm diameter
6	100	4516	
7	100	4635	
8	100	4785	
9	100	4798	
10	100	4895	
11	150	4344	
12	150	4404	
13	150	4453	4562 m/s in 150 mm diameter
14	150	4460	
15	150	4837	
16	150	4876	
17	200	4532	
18	200	4603	
19	200	4607	
20	200	4610	
21	200	4626	
22	200	4672	
23	200	4675	
24	200	4682	4790 m/s in 200 mm diameter
25	200	4687	
26	200	4783	
27	200	4789	
28	200	4941	
29	200	5007	
30	200	5015	
31	200	5024	
32	200	5078	
33	200	5105	

5.0 Analysis and Discussion

The variation of VOD of explosives as a function of charge diameter is well established from the tests of unconfined VOD at different charge diameters (Mohanty, 2013; Konya and Walter, 1990). Hypothetical curves showing variation of VOD with charge diameter for confined charges of bulk ANFO are also known (Jemino et al., 1990). On the basis of available knowledge, suitable non-linear functions were applied for data analysis to derive predictive models that could be used for further analysis.

The intrinsic non-linear relation between dependent and independent variable has been evolved on the basis of adjusted coefficient of determination, mean square error and sum square error by selecting exponential function, power function, logarithmic function, moving average function and polynomial function. It was observed that power function described the best fit estimator line with high correlation coefficient and least error. A generalized relation between in-the-hole VOD of explosives and borehole diameter can be mathematically expressed as follows.

$$VOD = KD^a \quad (1)$$

Where D is the blasthole diameter and K &"a" are the site constants.

It can be further observed that for any explosives material of same composition, particle size, density and degree of energy release characteristics, the measured in-the-hole VOD of explosives is directly proportional to the blasthole diameter. The relations between borehole diameter and in-the-hole VOD of explosives obtained for three mines are shown in Figures 4, 5 and 6. Using the known non-linear function, it is thus possible to establish the relation between VOD and blasthole diameter, even without having adequate measured data which was extremely difficult under production environments.

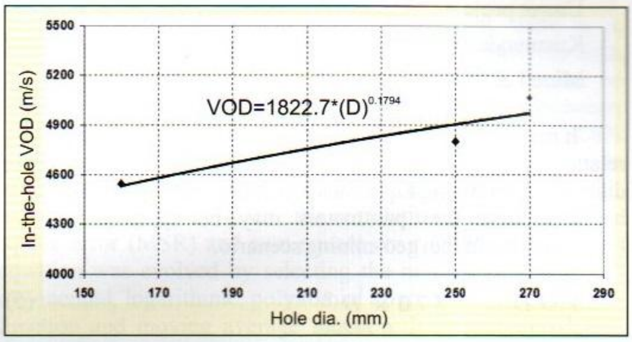


Figure 4 - In-the-hole VOD of Explosives vs. Borehole diameter Relation at Umrer Project

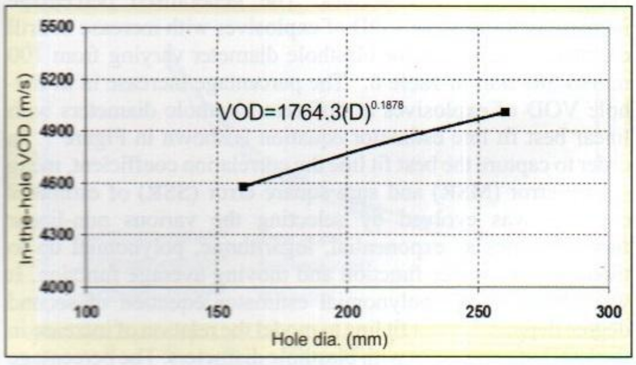


Figure 5 - In-the-hole VOD of Explosives vs. Borehole Diameter Relations at Kusmunda Project

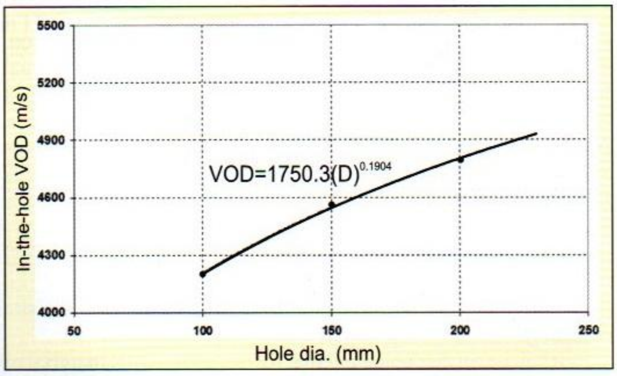


Figure 6 - In-the-hole VOD of Explosives vs. Borehole Diameter Relations at Mine-I &II of NLC

It is evident from the in-the-hole VOD of explosives and blasthole diameter relations that increase in borehole diameter results in a significant increase in detonation velocity of explosives column. The non-linear relations between borehole diameter and in-the-hole VOD of explosives for the selected mines may be best estimated by Equations 2, 3 and 4.

Umrer project : $VOD = 1822.7 \times D^{0.1794}$ (2)

Kusmunda project : $VOD = 1764.3 \times D^{0.1878}$ (3)

Mine I & II of NLC : $VOD = 1750.3 \times D^{0.1904}$ (4)

It may be observed that there exists positive and significant relation between in-the-hole VOD of explosives and blasthole diameter. Combining Equations 2, 3 and 4, a generalised relation between these two parameters may be approximated by Equation 5 for Indian geo-mining scenario.

$$VOD = 1770 \times D^{0.19} \quad (5)$$

The increase in drill diameter results in increase in in-the-hole VOD of explosives for any explosives material of same density, particle size, chemical composition and degree of energy release characteristics. The generalised percentage increase in in-the-hole VOD of explosives with increase in drill diameter is tabulated for blasthole diameter varying from 100 mm to 381 mm in Table 6. The percentage increase in in-the-hole VOD of explosives at different blasthole diameters with linear best fit line estimator equation is shown in Figure 7. In order to capture the best fit line the correlation coefficient, mean square error (MSR) and sum square error (SSR) of estimator equation was evolved by selecting the various non-linear function types as exponential, logarithmic, polynomial up to three degree, power function and moving average function. It was observed that polynomial estimator equation of second degree depicts the best fit line to model the relation of increase in the VOD of explosives with blasthole diameters. The percentage increase in the VOD of explosives at different blasthole diameters with non-linear best fit estimator equation is shown in Figure 8.

Table 6 - Computed increase in the VOD of Explosives for Various Blasthole Diameter

Drill diameter (mm)	Computed % increase in in-the-hole VOD of explosives
150	8
160	9
200	14
250	19
260	20
270	21
311	24
381	29

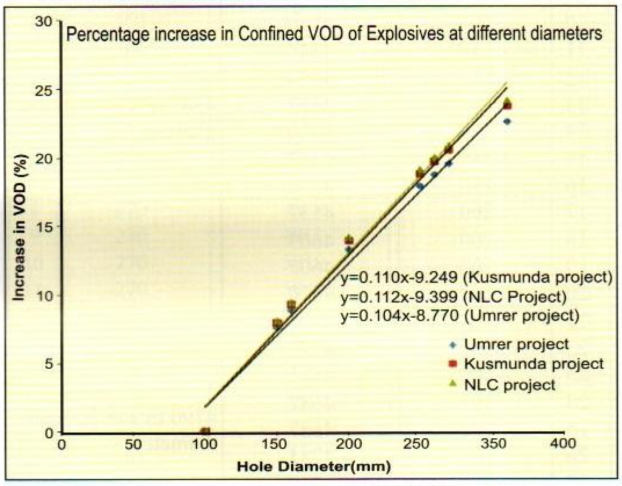


Figure 7 - Percentage increase in In-the-hole VOD of Explosives at different Blast Hole Diameters with Linear best fit line Estimator Equation

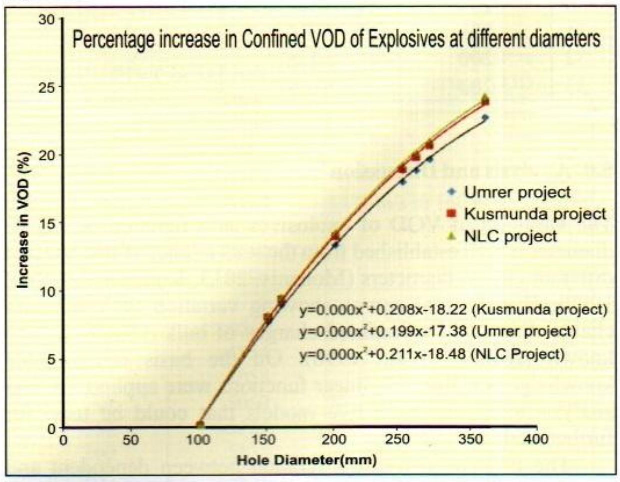


Figure 8 - Percentage increase in In-the-hole VOD of Explosives at different Blast Hole Diameters with non Linear best fit Estimator Equation

It is obvious that the minimum diameter at which the rate of increase in confined VOD becomes zero denotes the threshold condition of blasthole diameter above which the rate of increase in detonation pressure and explosive energy becomes zero due to energy release characteristics. When the explosive reaches the maximum energy release characteristics, the rate in increase in confined VOD and detonation pressure becomes constant. It was observed that the threshold diameter for achieving maximum energy release characteristics in blasthole is also site-specific. It was observed from case study mines that after 200-250 mm, the maximum explosive energy release characteristics is achieved in case of emulsion explosives having chemical gassing. However, when the blasthole diameter is more than 200 mm, it releases more chemical energy to rock mass but explosives energy release characteristics gets saturated. The first derivative test has been used to compute the maximum diameter where the explosives energy release characteristics gets stationary. As per the first derivative test, a real-value function f defined on a domain X has a global (or absolute) maximum point at x^* if $f(x^*)>f(x)$ for all x in domain X. As the rate in increase in VOD is a continuous real valued function with a compact domain, it will have a definite maximum point as per the rule of Fermet technique of absolute extremum. Table 7 shows the diameter for achieving energy release characteristics in any blasthole. The dependent variable 'y' refers to the increase in VOD and independent variable x refers to the blasthole diameter.

Table 7 - Diameter for Achieving Energy Release Rate (ERR) in Blastholes

Name of mine	dy/dx	Nature of dy/dx	Diameter for achieving ERR
Kusmunda Project	dy/dx=0.208	dy/dx>0; dy/dx>0 for x>0.208 m and dy/dx< 0 for x< 0.208 m	208 mm
Umrer Project	dy/dx=0.199	dy/dx>0; dy/dx>0 for x>0.199 m and dy/dx< 0 for x< 0.199 m	199 mm
NLC Project	dy/dx= 0.211	dy/dx>0; dy/dx>0 for x>0.211 m and dy/dx< 0 for x< 0.211 m	211 mm

As the surface mines are approaching close to inhabitants, it would be prudent to control or regulate the explosives charge per delay and per hole. Majority of coal mines (>95%) in India is using chemically gassed emulsion as explosive product, where 200-250 mm may be considered as the optimal blasthole diameter for achieving maximum explosives energy utilization.

The slope of the change in the VOD of explosives with blasthole diameter may be approximated by the following relation for Indian geo-mining scenario.

$$\frac{dVOD}{dD} = 331 \times D^{-0.81} \qquad (6)$$

The change in confined VOD i.e. d(VOD) with increase in blasthole diameter d(D) for all the three mines is shown in Table 8 and in Figure 9.

Table 8 - Increase in Confined VOD with Increasing Blasthole Diameter

Blasthole diameter (mm)	Increase in confined VOD with increasing diameter i.e d(VOD)/ dD		
	Umrer project	Kusmunda project	NLC project
100	7.5	7.9	8.0
150	5.4	5.7	5.8
160	5.1	5.4	5.5
200	4.2	4.5	4.6
250	3.5	3.7	3.8
260	3.4	3.6	3.7
270	3.3	3.5	3.6
311	2.9	3.1	3.2
381	2.5	2.7	2.7

The data analysis also demonstrated that there is a significant increase in the measured VOD of explosives with increasing blasthole diameter. The non-linear best fit line or estimator equation (Figure 9) shows the relation between d(VOD)/d(D) for various blasthole diameter (where d(VOD) refers to differential of VOD and d(D) refers to the change in blasthole diameter). In order to capture the non-linear best fit estimator equation between the correlation coefficient, mean square error (MSR) and sum square error (SSR) of estimator equation was evolved by selecting the non-linearity types as exponential, logarithmic, polynomial up to three degree, power function and moving average function. It was observed that power function depicts the best fit line to model the relation between d (VOD)/d(D) versus blasthole drill diameter.

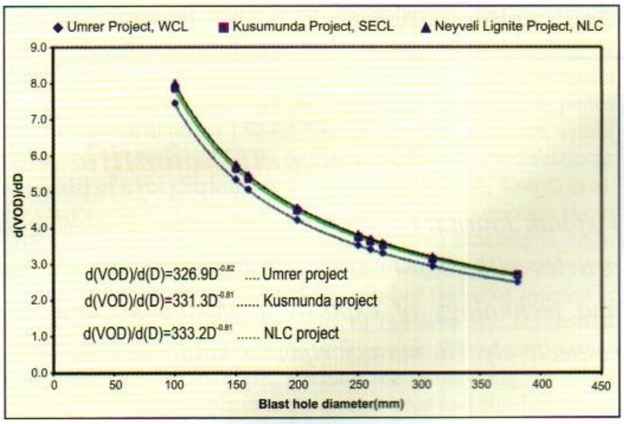


Figure 9 - Non Linear Estimator Equation showing Relationship between d(VOD)/D(D) and blasthole diameter

The minimum diameter for steady state detonation velocity for large diameter non-permitted and bulk explosives product may be approximated by solving the linear estimator (Table 8). Fig. 7 shows the increase in VOD versus blasthole diameter showing the linear estimator equation. By equating the equation equal to zero, the minimum diameter for achieving steady state VOD was estimated (Table 9).

Table 9 - Estimation of Minimum Diameter for Steady State VOD

Name of the mine	Relations between in-the-hole VOD and drill diameter	Minimum diameter (mm)
Umrer Project, WCL	VOD = 0.104 *D - 8.770	84.3
Kusmunda Project, SECL	VOD = 0.110 *D - 9.249	84.0
Mine I & II, NLC	VOD = 0.112 *D - 9.399	83.9

6.0 Conclusions

The measurements of in-the-hole detonation velocity of chemically gassed bulk emulsion explosives for different blasthole diameters and the predictive models developed in this study helped in estimating minimum and maximum charge diameter without having conducted field measurements for a wide range of blastholes which is actually impracticable under production environments. The study showed that the maximum blasthole diameter at which explosive energy release rate was achieved under confined condition was found to be 200-210 mm. It suggests that mine planners as well as operators may restrict the maximum blasthole diameter to 200-250 mm for shovel dumper combination where bench height is limited and blasting, in most cases, is to be conducted in the vicinity of habitants. The minimum diameter for achieving steady state VOD for the emulsion explosives was approximately 84 mm. As draglines are used primarily in Indian coal mines to excavate the parting or inter burden between the coal seams having a thickness of 30-40 m, blasthole diameter of 250-381 mm may be used for dragline benches.

7.0 Acknowledgement

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Status of Blasting Research in India




H. S. Venkatesh **A. I. Theresraj** **G. Gopinath** **R. Balachander**

Scientist

Rock Blasting & Excavation Engineering Department, National Institute of Rock Mechanics, Bangalore - 560016

1.0 Introduction

Blasting is the backbone of the mining, hydel and infrastructure industry. Over the period of time the blasting industry has evolved and India too has caught up with the rapid pace of the technological developments of the industry. Application of technology grew exponentially during the past 25 years and NIRM too has been playing a major role since its inception in 1988. Nineties saw the globalisation in India and the mining industry too dreamt big. The explosive and equipment industries geared up to meet the National supply demands. Indigenous technologies and global tie upsstrived and Indian research too supplemented the excavation industries growth.The Rock Blasting & Excavation Engineering department at NIRM has been providing innovative solutions to challenging problems in blasting for various mining, hydroelectric and civil engineering projects for the past 25 years. Apart from providing solutions to conventional blasting problems, NIRM has been providing customized solutions to Metro rail projects, controlled blasting problems, graded material requirements (rip rap / armour rock / aggregate), pre-splitting for high wall stability, underground caverns (power houses / crude & gas storages), TBM, integrating blasting and other excavation techniques etc. The department is carrying out the preparation of blasting related pre-construction reports, method statement, proof checking etc. The Rock Blasting & Excavation Engineering Department has provided technical solutions in more than 150 projects (Sponsored and S&T), published over 100 technical papers and extended its services to more than 90 organizations. An attempt is made in this paper to present the current status of blasting research in India and its passage through 25 years by reviewing blasting instrumentation and some important case studies.

2.0 Details of Blasting Instrumentation

In order to assess and evaluate the blasting results many organizations in India are conducting research and Table 1 gives the status of Indian practices vis-à-vis the global practices. The details of the instruments and the general procedure followed in the blasting studies is discussed in the sections below:

2.1 Ground Vibration and Air Overpressure

The instruments used for monitoring blast vibration (ground vibration and air overpressure) is a seismograph. There are many manufactures who supply the seismographs and one of the versatile instrument with NIRM is the Minimate Plus Seismograph from Instantel, Canada (8 channels). Conventional tri-axial geophones are used for monitoring ground vibration at farther distances and while monitoring ground vibration at near field, high frequency tri-axial geophones (28Hz to 2KHz) are used. In order to study the response of rockmass, sensors are mounted on bolts anchored in the rock mass. The seismographs are microprocessor-based, portable units and each unit consists of a standard external tri-axial transducer for monitoring ground vibration and a mike for measuring air overpressure.

Apart from ground vibration, air overpressure from blasting is generally an annoyance problem and may not cause damage but may result in confrontation between the operator and those affected. Air overpressure is not simply the sound that is heard, but it is an atmospheric pressure wave consisting of high frequency sound that is audible and low frequency sound or concussion that is inaudible. The weakest component of structures that may be affected is glass panes which is unlikely unless air overpressure levels exceed 160 dB. The air overpressure levels at critical structures are restricted to below 133dB being the permissible level as per US Bureau of Mines and IS code.At sound pressure levels below 130dB there will be audible rattle, mainly from windows and doors and from objects standing on shelves. With increasing amplitude, window panes begin to break at about 152dB. Most windows in an area would break at amplitude of 172dB, and structure damage would occur at 182dB or over (Siskind et al. 1980, Anon. 1998, Konya et al. 1990). People living nearby blasting sites often complain about ground vibration if the noise produced from blasting is high, they feel that the vibration is high. Although it is not directly related to increased overpressures, another factor of interest is the time related to the occupancy of the area and residential activities. Certain times may be unfavorable for the residents of a given area, such as night, evening, early morning, or times when most of the people in the area are home and conditions are relatively quiet.

Table 1 - Status of Indian Practices vis-à-vis Global Practices

Activity	Global Status/ Operating Procedures	Indian Status/ Operating Procedures
Blast Design	Empirical formulae Regional design considerations and local database	Empirical formulae Regional design considerations and local database
	Measurements	
	Digital cameras High speed camera Continuous VOD measurement Through commercial image processing tools Laser face profiling Signature hole analysis Bore hole pressure measurements Commercial Blast design software's Numerical modeling/Simulation study– Auto Dyne/3DEC	Digital cameras High speed camera Continuous VOD measurement Through commercial image processing tools Laser face profiling Signature hole analysis Bore hole pressure measurements Commercial Blast design software's Numerical modeling/Simulation study – Auto Dyne/3DEC
Ground Vibration & Air Over Pressure	Seismographs with AOP measurements Distance measurements with GPS/Conventional laser based survey Field measurements as per ISEE Standards differ country wise	Seismographs with AOP measurements Distance Measurements with GPS/Conventional laser based survey Field measurements as per ISEE IS Code 14881 : 2001* and DGMS (Tech) (S&T) Circular No. 7 of 1997**
Rock Mass Damage studies in U/G Cavern & Tunnel	Conventional vibration monitoring Half cast factor Monitoring with High frequency geophone Bore hole camera Rock characterisation pre & post through seismic survey Strain measurements	Conventional vibration monitoring Half cast factor Monitoring with High frequency geophone Bore hole camera Rock characterisation pre & post through seismic survey Strain measurements
Over break control in U/G & Tunnels	Customised perimeter explosive used Bulk explosives for U/G applications Electronic detonators	Not readily available in India Just introduced in India Just introduced in surface mines. Still using conventional electric detonators and shock tubes.
Controlled blasting in urban environment	Rubber mats and Rope mats Shock tubes/electronic detonators	Rubber mats. Additionally we use link mesh, sand bags, Rubber tyres. Shock tubes

**Anon (2001)* ***Anon (1997)*

2.2 Structural Response

In order to assess the structural response it is essential that we have the vibration measurements done at different locations in a structure (at the foundation and on the upper floors) and the sensors have to trigger at the same time. With this we can study the amplification, role of frequency, attenuation etc of the vibration and the response of the structure and study the damages (creation of new cracks, extension of old cracks etc). The conventional seismographs have standalone geophones and placing multiple instruments leads to difference in arrival times needing synchronising through software. Minimate Pro6 and Series IV is one of the instruments used for monitoring structural response, consists of two standard tri-axial geophones to monitor vibration from the source at two different locations and gets triggered at the same time.

Generally houses contain numerous cracks of which the owner is unaware and which continue to increase in number and size each year with passage of time. Studies have indicated that the formation and extension of cracks is also a function of time and thermal variations. People are concerned that the existing cracks widen or new cracks are formed in their structure due to tunnel blasting. In India generally a permissible limit 5mm/s is recommended (Kutcha and cement and brick construction) and in cases structures with RCC and if the frequency is above 8hz, a higher limit of 10mm/s as per DGMS standards are recommended. Adrian et al. (2002) from their studies with regard to structural response of brick veneer houses to blast vibration observed from their experiments in Australia that environmental strains and rainfall contribute to the extension of existing cracks in a structure and the strain induced due to these environmental loads upon conversion to equivalent PPV are much higher than from blasting. They reported, no observable damage occurred until the ground vibration levels (PPV) exceeded 70mm/s. The damage at vibration levels of 70 - 220 mm/s was confined to the lengthening of existing cracks and the formation of new cracks in plasterboard. Studies on structural response to blasting in India by (Adhikari et al. 2005) have shown that no new damage or extension of existing cracks were observed in residential structures at PPV exceeding just above 20 mm/s.

2.3 Human Perception to Ground Vibration

Human beings are far more sensitive to ground vibrations and noise than structures. People inside buildings will respond differently than people outside and will respond more adversely inside their own houses than when they are inside other buildings. People tend to complain about ground vibrations even when the vibration level is below the minimum permissible limit of 5mm/s (Anon, 1997). One of the most important factors for complaining is the presence of secondary sounds such as rattling windows and doors. The threshold of perception for motion (without sound effects) is roughly 0.51mm/s (Anon, 1998) for most people at typical blasting frequencies. During a recent study by NIRM at Bangalore, blasting in rock was carried out in different locations of an excavation area. In total 27 blasts were carried out during the field studies period of 12 days. The closest and farthest distance between the residence at Fern Paradise layout and blasting location was 30m and 115m respectively. It is worthwhile to mention that though the vibrations were limited below the permissible limit of 5mm/s at the structures belonging to Fern Paradise, the human perceptions were that whenever the vibrations were below 1.5mm/s there were no complaints from the residents, and when the vibrations were between 1.5mm/s and 2mm/s they were uncomfortable and when the vibrations were above 2mm/s they complained of excessive vibrations (Balchander et al. 2014).

2.4 Flyrock Studies

Viewing the blasts in high quality slow motion will allow the designer to make decisions for improvements in rock breakage, movement, flyrock control and timing. Now a days the conventional low cost HD digital cameras are being used to capture the blasting in real time and are analysed through motion analysis software (commercially available or evaluation versions). This kind of analysis is more than sufficient to review and assess the blast designs (Figure 1). Conventional low cost HD cameras are filming at 200 fps and these are proving to be equally helpful for recording high speed events at a low cost. However, specific studies with regard to measurements like flyrock trajectory and velocity, burden movement, stemming ejection velocity etc need high speed cameras. Most of the high speed cameras have 8 s recording duration (upto 10,000 fps) but cameras with higher duration too are available. In order to capture high speed events indefinitely these cameras store the event in a circular buffer with a pre-trigger setting. The cameras are armed through a remote switch that activates along with the initiation. In this way no event is missed. As most of the blasting events are captured from a distance of about 300 m and above, during clear sunny days 1000 to 2000 fps settings is good. Beyond which the clarity generally deteriorates.

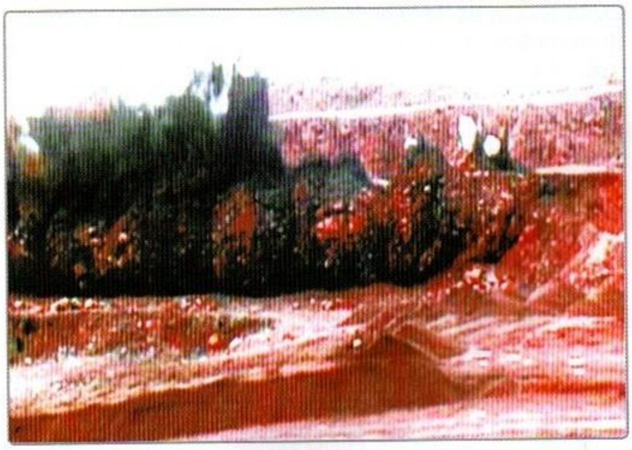


Figure 1 - Observation of a Blast using Conventional Video Camera

2.5 Measuring Velocity of Detonation of Explosive

A large quantity of explosives is used for blasting in surface mines and quarries. The explosives are characterised by their properties such as strength, density, fume characteristics, water resistance, velocity of detonation (VOD), etc. Of these properties, the VOD is directly linked with the performance of the explosives. VOD of an explosive is defined as the rate at which the detonation front travels through a column of explosive. Every explosive has an ultimate or ideal detonation velocity known as steady state velocity of the explosive. VOD of an explosive is influenced by its chemical composition, diameter of the charge, confinement, temperature, degree of priming, etc. Evaluation of a blast design is carried out with the assumption that the explosives have performed as per the specifications, which may not be true in all cases. A reduction in the VOD will result in a reduction in the detonation pressure as well as in the availability of the shock energy of the explosive. An explosive will detonate reasonably when suitably confined and initiated by a high explosive of sufficient intensity and the reaction progresses along the explosive column with a speed equal to the VOD. The explosive pressure Pe which denotes the gas pressure applied to the borehole walls just after detonation is approximately one-half of the detonation pressure. The detonation pressure is directly proportional to the VOD of an explosive and any change in VOD is bound to affect the performance of a blast. During the early 1990s, NIRM carried out extensive VOD field measurements using discrete system in India. However, the discrete measurements did not provide comprehensive information along the charge length as the calculated VOD was only the average velocity of the explosive between two points. Subsequently when continuous systems were commercially available, NIRM carried out exhaustive studies to study the influence of various explosive and blast design parameters on VOD of an explosive (Venkatesh et al. 2001).There are instruments like Micro-trap, Data-trap, VODmate etc to monitor explosives continuous VOD in real time. These instruments are capable to measure the VOD of explosives in single or multiple holes. When recording VODs, the recorders output a low voltage (< 5 VDC) and an extremely low current (<50 mA) to the probes. This low excitation signal ensures that the instrument will not prematurely initiate explosives and /or detonators. These instrument measure the rate of change in probe cable length (known resistance) which is analysed through a software provided with the instruments to plot the VOD graphs and carry out further analysis of the traces. A typical experimental setup and a VOD trace is shown in Figure 2.

Now a days we have integrated instruments to measure the borehole pressure along with other measurements. Datatrap II is one such advanced data acquisition system that records the real time VOD of the explosive, delay time of the delay detonators, pressure, strain etc. It can also record near field blast vibrations using high G uniaxial and tri-axial accelerometers. The instrument is capable to record VODs of up to 8 explosives samples simultaneously and up to 32 blastholes and determine the delay times between holes and decks of explosives. Using Datatrap II it is possible to connect accelerometers (or other sensors like pressure probe, strain gauges) on several channels and VOD on other channels to determine the explosives performance and the effects on the rock walls simultaneously in one blast on a common time base.

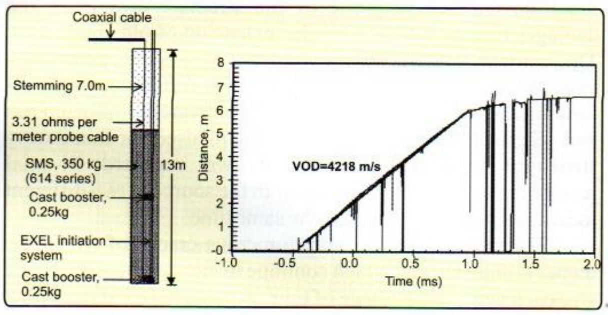


Figure 2 - VOD Monitoring Field set up and a VOD Trace

2.6 Rock Mass Damage

Ground vibrations having sufficient energy can cause damage to the rock mass. The extent of damage is not solely a function of vibration level but is also related to site-specific parameters such as rock strength, geological features, ground support system, etc. As the severity of blast vibration increases, the damage done to the rock mass also increases. Various codes and standards have been prescribed for ground vibration limits in different countries for surface structures. There are no universally recognized standards for blast vibration for underground structures. Some researchers have concluded that the extension of existing cracks in the rock mass is limited to a distance of 80 to 108 blasthole diameters (charge diameters) or 4.5 m at the most in case of underground excavations. Particle velocities at this distance were 300 to 400 mm/s. Venkatesh et al. 2005 observed that vibration levels above 212 mm/s have resulted in minor spalling of the rock mass in the drainage galleries and the construction adits of an underground cavern in Himalayan rock mass. Some researchers have correlated induced tensile stress developed by particle velocity with that of the tensile strength of the rock mass. Richards and Moore (2002) observed in a coal mine that strain induced by blast vibrations leading to damage was about 10 percent of the tensile failure strain of the rock mass. Ramulu and Sitharam (2010), carried out research work on the effect of repeated dynamic loading imparted on the jointed rock mass from subsequent blasts in the vicinity at a hydroelectric project. The blast induced damage was monitored by borehole extensometers, borehole camera inspection surveys and vibration measurements using tri-axial geophones. There observations also showed that the rock mass damage was limited to less than 4m from the tunnel. Thus, there are different methods for damage assessment and they are: visual inspection, scan line surveys, scaling time, empirical rock mass rating systems, sounding of roof and walls, geophysical methods, bore hole video observation, near field vibration analysis, strain measurement, P-Wave velocity measurements, half cast factor etc. of late bore hole camera observations of pre and post blast crack presence/propagation/creation and their correlation with near field vibration measurements are becoming popular in assessing the rock mass damages.

2.7 Fragmentation Assessment

Fragmentation in opencast mines is a key issue and the productivity of the mines has a direct dependence on the fragment size being produced from blasting. The fragment size and uniformity of the blasted material, effects the cost of the 'unit operations of mining' and thereby the productivity. Physical counting of fragments can correlate very closely to the actual size distribution in the muckpile but it is very cumbersome, time consuming and exhaustive. Other means is the sieving of the muck pile and this too is time consuming, expensive, intrudes into the mining operations, shall alter the fragment size distribution etc. Considering this, researchers have been working over a period of time to evolve methods to assess fragmentation. Image processing techniques proved to be suitable and effective in establishing the fragment size distribution in a muckpile. Figure 3 shows the boundary zoning of the fragments in an image and an output comparing the fragment size distribution from field experiments at a mine. Of the image processing softwares developed for the assessment of fragmentation over the period, WipFrag (Maerz et al. 1996), SPLIT (Kemeny, 1994) and Fragalyst (Raina et al. 2002) are commercially available.

2.8 Laser Profiling Survey System

Blast results are dependent on a number of parameters related to the rock, explosives, blast geometry, delay timing and initiation sequence. The knowledge of probable crest and toe burdens will help in designing the blast and also in proper deployment of drilling machines. The placement of front row holes would considerably affect the blast results and it may lead to flyrock, airblast, toe or even a blast failure. There are several methods to measure the burden against hole depth, but the most popular has been the fishing rod method. Even though the method is simple, it is time consuming and cumbersome. Now a days, microprocessor based rock face survey systems are available for this purpose. The laser profiler is a tripod mounted instrument designed to record inclined distance, horizontal and vertical angles during rock profiling operations. The target is viewed through an eyepiece and laser light is emitted through a transmit aperture and admitted through a receiver aperture. The laser system bounces a pulsed beam of laser off the rock face. The instrument uses a pulsed semiconductor laser diode system which makes it capable of ranging rock up to 400 m and targets up to 10,000 m fitted with multi-retro reflectors. An internal electronic clock measures the `time of flight' of the pulse and the distance is calculated from the speed of light. Simultaneously vertical and horizontal angles are measured indicating the direction of the observation. Multiple observations across the face are stored and filed automatically in the instrument's memory. This is retrieved and processed at the site office through analysis program (Figure 4). These profilers can also profile the blasted muck but this needs a separate analysis program for characterizing the muckpile.

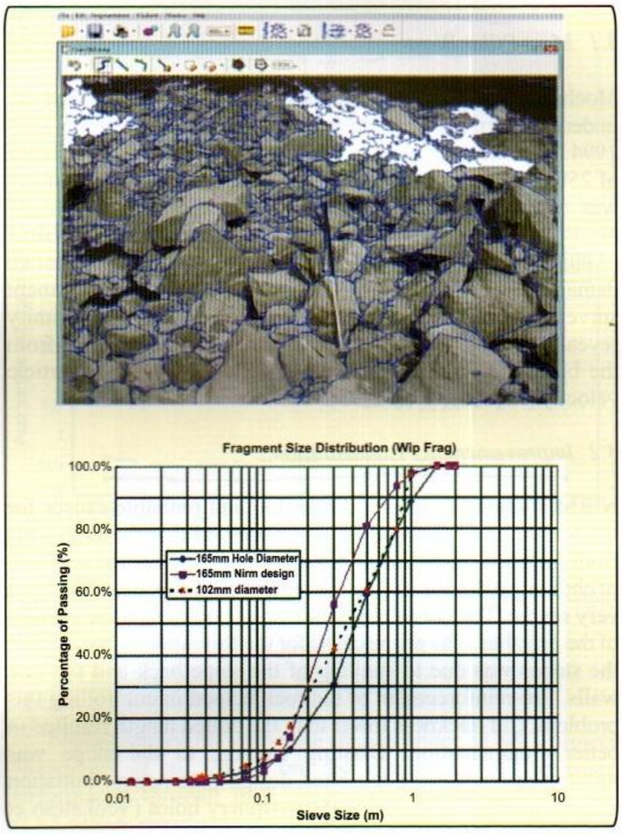
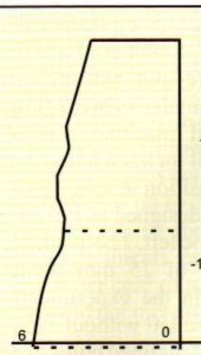


Figure 3 - Showing the Fragmentation Analysis using Image Processing Technique



Point	Depth	Burden
1		
2	1	3.9
3	2	4.1
4	3	4.3
5	4	4.5
6	5	4.3
7	6	4.4
8	7	4.4
9	8	4
10	9	3.9
11	10	4.5
12	11	4.9
13	12	5.1
14	13	5.3
15	13.2	5.4

Figure 4 - Profile for one of the Holes with 3.7 m Offset

3.0 Case Studies in Blasting

NIRM and other researchers have contributed in providing solutions to practical blasting problems in India. Some of the important case studies over the past 25 years are briefly presented below.

3.1 Mass Pillar Blast

Mochia mine fired 145 tonnes of explosive to blast an underground pillar to yield 0.55 millon tonnes of ore in June 1994. To protect the main mine structures (situated at a distance of 250 to 350m from the blast) the maximum charge per delay was restricted to 2300 kg. Vibrations produced from stope blasts, development and pillar blasts were monitored by NIRM (Adhikari et al. 1993). Post-blast observations revealed that no damage was caused to the structures. The damage assessment survey of the mine workings situated in close proximity revealed a general trend in consonance with the distance from the blast and found to be well correlated with peak particle velocity (Rajmeny et al. 1995).

3.2 Improvement in Fragmentation

NIRM studied the nature, dimension and probable causes for the formation of boulders. It was observed that the fragments from the blasts were usually smaller than 1 m, but the problem of choking at the chutes due to boulders in shrinkage stopes was very severe. There was heavy pile up of boulders in the vicinity of the grizzlies. The prime cause for the formation of boulders in the stopes was due to spalling of the stope back and the side walls. Pre-reinforcement of the rock helped in controlling this problem. Cut thickness lower than the bolted length resulted in better fragmentation. Blasting damage to the stope was minimised by altering the blast design parameters, initiation system and lightly charging the periphery holes (Venkatesh et al. 1992).

3.3 Pre-Splitting

Pre-splitting was envisaged for achieving steeper slope angle at Rampura Agucha mine in India. Singh et al. (2009) designed and successfully guided the pre-split blasting operations to ensure stable pit slopes with minimal over break (Figure 5).

Initially the available drill machine was of 115 mm diameter and was not able to drill inclined holes. A master plan of the vertical pre-split holes position at spacing of 1.2 m was prepared. The pre-split line was designed at 1 m away from the final crest line from the berm to be left. The available explosive was in the cartridge diameter of 25 mm which provided decoupling by factor of 4.56. In the experimental trials the mouths of the pre-split holes were left without explosives from 0.8 to 2.7 m. In the latter stage the inclined holes of 80°, 70° and 60° with 115 mm diameter were experimented. The charge factor of 0.44 to 0.90 kg/m was experimented depending upon the rock types. The best results were encountered when pre-split holes were drilled with 60° inclination and the top portion were uncharged by 2.2-2.7 m.

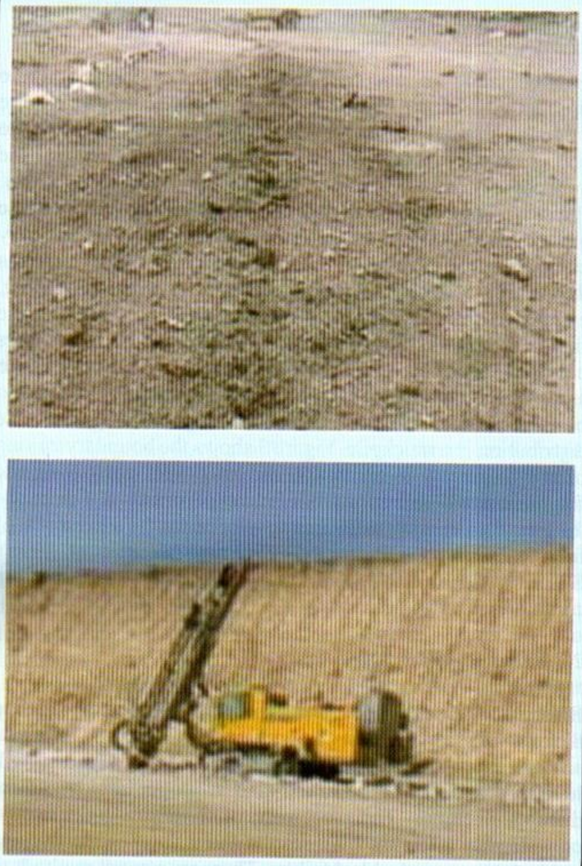


Figure 5 - Pre-split Blasting at Rampura Agucha Mine

In order to minimise the volume of excavation to construct a surface nuclear power plant in proximity to existing nuclear power plant in India it was decided to have vertical slopes. The stability of these high-walls become very important as they have to serve for decades. Therefore damage to the wall rock was controlled by adopting pre-split blasting. Based on the suggested blast designs by NIRM about 1.6 million cubic meter of hard rock was excavated for site grading and foundation excavations in close proximity to an operating nuclear power plant. The suggested blast design for pre-splitting controlled the damage to the rock mass in laminated sandstone and ensured stable 14 m high walls (Figure 6). In total, 45,000 m^2 was successfully pre-split using 115 mm dia holes from about 200 blasts. The average half cast factor (HCF) achieved with a spacing of 0.8 m and a charge density of 0.55 kg/m2 was 80% (Gopinath et al. 2012).

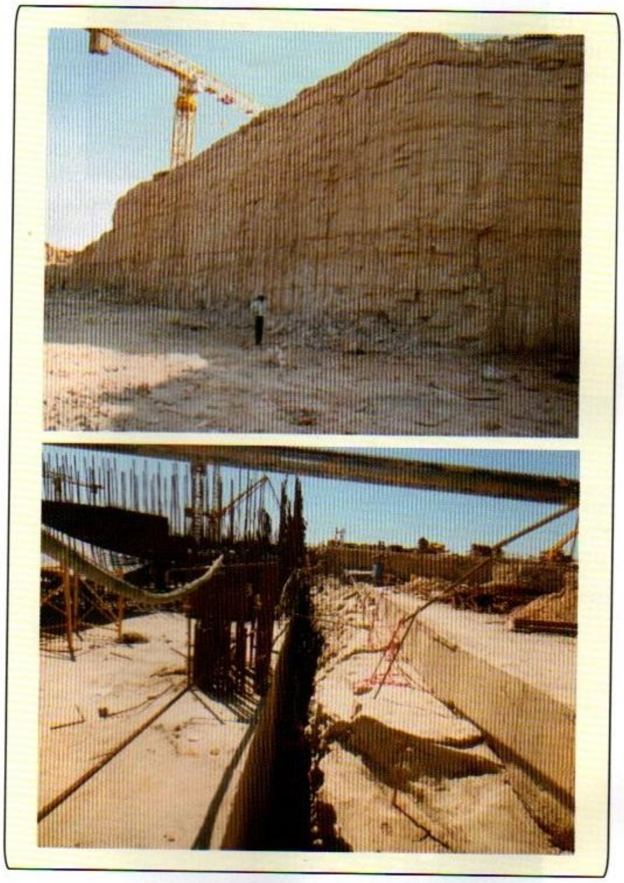


Figure 6 - Pre-split Blast Wall and the Subsequent Civil Constructions of the Nuclear Plant

3.4 Influence of Total Charge on the Intensity of Ground Vibrations

There are apprehensions with regard to a number of factors that influence the generation, propagation and intensity of ground vibrations. However, there were conflicting opinions with regard to the influence of the blast size on the intensity of ground vibrations. NIRM carried out extensive field studies in an opencast coal mines in India and computer simulation study(Venkatesh, 2005). Studies clearly indicated that the total explosive charge in a blast has insignificant influence on the intensity of ground vibrations, for distances between 100 m and 3000 m (Figure 7).

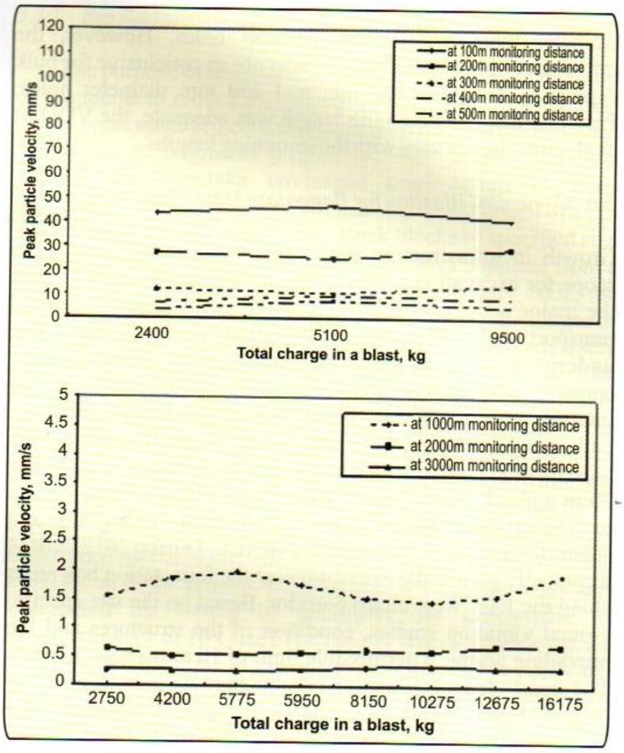


Figure 7 - Peak Particle Velocity vs Total Charge for a Constant Maximum Charge per delay

3.5 Evaluation of Explosives Performance

NIRM carried out elaborate studies under an S&T project (Venkatesh et al. 2001) on the evaluation of explosive performance through in-the-hole VOD measurements. The VOD values monitored for cartridges explosives were higher than those quoted by their manufacturers. In case of bulk explosives, the VOD values were almost matching with the quoted ones. It could be concluded from the experiments that any increase in the quantity of primer beyond the recommended levels did not increase the VOD of the explosives. Single point priming was sufficient to reliably initiate and sustain the steady state VOD of explosives up to 10m long column without any additional booster charge. The contamination of SMS explosive while charging resulted in lower VOD. The analysis of VOD records in dragline benches confirmed that SMS explosives can be loaded in blastholes up to depth of 30m without the risk of attaining dead density of the explosive due to hydrostatic pressure. The experiments conducted with SMS explosives containing 0 to 9 per cent of aluminium powder indicated that the VOD values did not increase with the increasing aluminium percentage. The experiments in completely wet holes were not successful due to inefficient shorting of probe cable. The VOD decreased by about 25 per cent when SMS 654 had a sleep time of 25 days. The VOD value of ANFO was greater in 250 mm diameter than in 115 mm diameter holes. However, the influence of blast hole diameter was not so conclusive for bulk explosives tested in 150 mm and 250 mm diameter holes. Provided that the stemming length was adequate, the VOD of explosives did not vary with the stemming length.

3.6 Controlled Blasting for Bangalore Metro Rail Project

Growth in infrastructure projects in India has created huge scope for excavation activities throughout the country. One of the major activities in any city is the development of public transport and metro rail is the most preferred one. The underground component of metro rail predominantly constitutes the tunnels and the stations in soil and hard rock. The tunnels were made by tunnel boring machines while the underground stations were planned to be excavated by drill-blast method (cut & cover). In general, each station box is about 20 m wide, 272 m long and 20 m high. NIRM carried out the preliminary blasting studies at an alternate site during 2008 and submitted a method statement to BMRCL. During 2012, NIRM technically guided the excavations at the four station box areas along the East-West metro corridor. Based on the site specific ground vibration studies, condition of the structures and the prevailing norms, a permissible limit of 10 mm/s was decided. The suggested muffling in conjunction with heavy rubber blasting mats restricted the flyrock distance within10 m. The blasthole diameter was restricted to 45 mm while the maximum charge per delay was kept below 2.5 kg. The specific charge was between 0.5 and 0.6 kg/m3. Bench heights were gradually increased from 1.5 to 3.0 m and a production higher than the targeted production of 300 m3 per day was achieved many times(Figure 8).In total about 500 controlled blasts were successfully conducted by NIRM during the study period (Balachander et al. 2011). Controlled blast designs and the guidance on sequencing of benching operations facilitated to avoid the excavation of a launching shaft for the TBM at Sir M V Visveshwaraya station area. This brought down the need for hard rock excavation and also saved time as the TBM launching could be done from the station area itself.

3.7 Shaft Sinking

Excavation of shafts has been a difficult, costly and time consuming process. In recent times there has been some mechanization, however, the conventional and semi mechanized methods still seem to dominate. Different methods have been followed for excavation of shafts and conventional drill blast methods is still the most opted method(Figure 9). NIRM was associated with the excavation of a surge shaft in a hydro electric project in Bhutan. About 900kg explosive per blast was used on a regular basis. An average advance of 3.2m per blast was achieved for a drilled depth of 3.5m. Unfavorable geological conditions encountered during excavation not only caused problems in excavation but also resulted in blockades which were successfully tackled (Venkatesh et al. 2004).

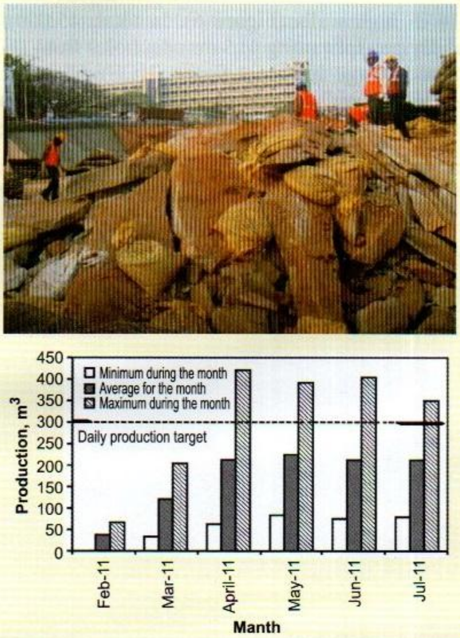


Figure 8 - Blasted Muck and Consolidated Production Details at Sir M V station

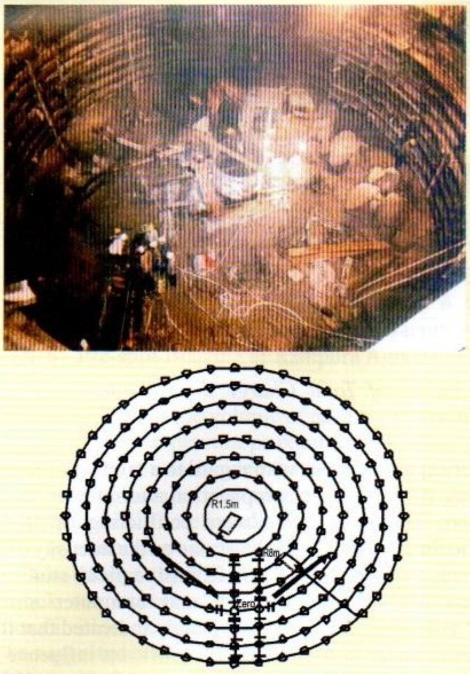


Figure 9 - Full Face Blasting of 16m dia Surge Shaft

3.8 Underwater Blasting

Underwater blasting forms a major part of rock dredging projects in ports. A rock dredging project covering an area of about 1,30,000m2 involving 4,00,000 um of hard rock mass was taken up in Tuticorin Port, India, in front of Berth No. 8. STADD Pro analysis was carried out for determining the natural frequency of Berth No. 8. Under water blasts were planned with varying configurations at different locations from the structure in order to maintain the vibration levels to within threshold values prescribed. In total 1900 underwater blasts were carried out using 95t of explosives (Sastry et al. 2013). Under water blasts should be designed judiciously, as any error has huge ramifications in terms of delay in project duration, cost escalation and on the performance of the dredging equipment. Continuous monitoring of underwater blasts with effective instrumentation immensely contributed in minimising the environmental effects but in generating data bank about the blast effects on structures too. Figure 10 shows the underwater blasting in progress.

Figure 10 - Underwater Blasting in Progress

3.9 Blasting Gallery

Extraction of seams thicker than 4.8m has always been technical problem for the mining industry and Blasting Gallery method of mining is considered to be one of the most economical and viable technology for thick seam extraction. In BG method, the entire seam thickness can be excavated in one lift by drilling a set of holes in a ring pattern with percentage of coal recovery ranging from 65 to 85%. BG method was initially introduced for extraction of already developed pillars at East Kartras Colliery (BCCL) and Chora-10 pit Colliery(ECL). It was subsequently extended for exploitation of virgin thick coal seam at GDK-10 Incline of SCCL. Induced caving by blasting (or in short induced blasting) has become an integral part of BG method for controlling the roof strata. CIMFR has been carrying out extensive research in the area of induced blasting for BG panels and has been guiding the industry in this regard.

3.10 Rip Rap

The purpose of blasting is normally to achieve smaller size of fragments to reduce the overall mining costs. In some case like in breakwater projects, the purpose of blasting is to produce bigger size of fragments (Figure 11). The Seabird project at Karwar in Karnataka envisaged construction of three breakwaters with a total length of 5.25 km with a height of 16 m and a base width of 120 to 130 m. Rock blocks of specified size gradations termed armourstone gradings were supplied from a nearby quarry on Aligadde hillock. During January 2002, the project was facing an acute shortage of certain weight ranges of armourstone. This shortfall in armourstone was adversely affecting the progress of construction of the breakwaters. The primary reason for this shortfall was that the quarry was unable to produce the armour sizes at the required rate of supply. The average quarry yield of armourstone (defined for this project as being from 1 to 10 t in weight) was about 23% while the production of rock pieces less than 1 t accounted for 77%. Increasing the yield of armourstone from the quarry was very crucial not only to reduce the cost but also to avoid delays in the completion of the project. Keeping this in view, this study was conducted by NIRM to maximise the production of armourstone (1 to 10 t size).The natural blocks suitable for the specified armourstone in the quarry was low due to joints and intrusions present in the rock mass. Furthermore, there was inevitable breakage of the natural blocks, reducing potential armourstone yields by approximately 15% due to quarrying operations including primary and secondary blasting. Despite strong influences of local geology, the yield of armourstone (1-10 t) increased to over 30% compared to pre-investigation period yield of 25 % (Adhikari et al. 2002).

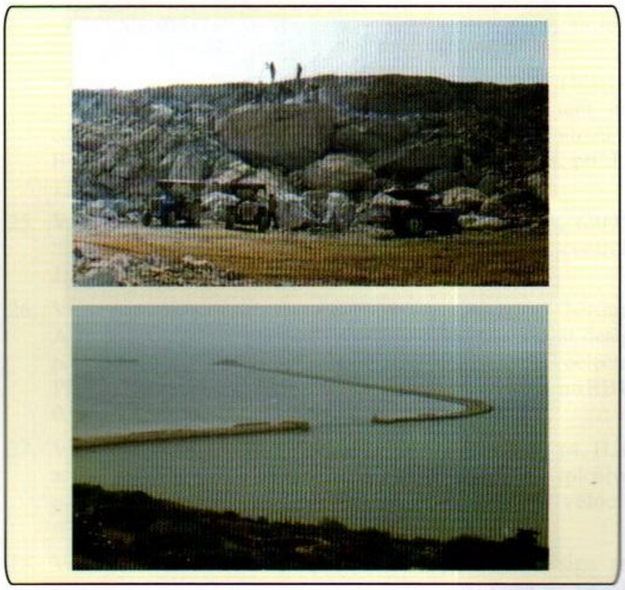


Figure 11 - Blasted Armour Rock and the Finished Break Water on the Sea

Indira Sagar Polavaram Hydro Electric Project (960MW) is to be constructed across river Godhavari, 42km upstream of Rajahmundry by the Govt. of Andhra Pradesh. As part of this project 2454m long earth cum rock fill dam across the river is to be constructed. The main dam is proposed to be constructed with rock fill material (Rip rap) of 150mm to 600mm and 500mm to 1000mm for revetment shall be obtained from excavation of spill way, power house etc. In order to maximise the output of the graded material from blasting, NIRM carried out preliminary site investigation and recommended the blast design parameters (Gopinath et al. 2013).

3.11 Tunnelling

In Karnataka twin tunnels through the hills adjacent to the Tungha Bhadra dam and under an operating railway line were being planned for road connectivity. The cover above these tunnels is about 14m. While blasting under the railway zone, the monitored ground vibration on the track was safe and were lower than the vibration levels due to passage of the train itself. The levels measured before and after blasting on the track in the railway zone showed insignificant ground settlement. Suggested blast designs and sequence of excavation in the tunnels ensured the completion of these tunnels under the operating railway line(Balachander et al. 2012) (Figure 12).

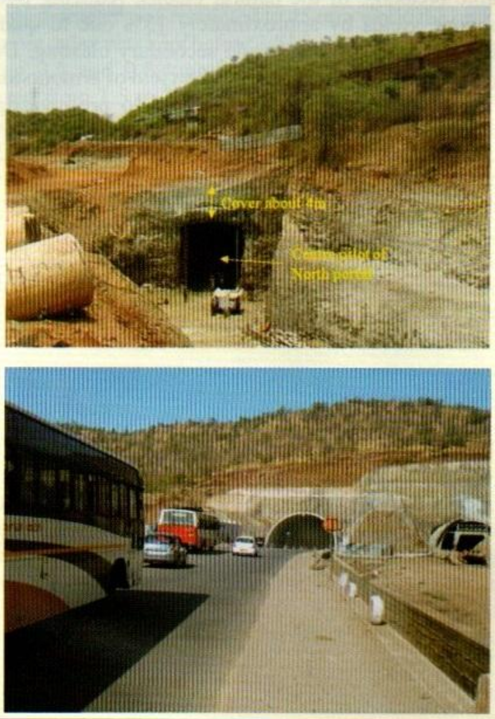


Figure 12 - The Tunnel under Construction and under Operation

3.12 Blasting at TBM Sites

The work of 6.75km long Dulhasti project head race tunnel of 8.3m excavated diameter was started with gripper type hard rock TBM. The rockmass was predominantly hard and highly abrasive quartzite. While tunnelling, the TBM was inundated with a water inflow of over 1000 l/s. The TBM could bore only 2.86km and finally was abandoned. The project has subsequently been completed by conventional D&B method. At the head race tunnel for Parbati Stage-II project, an incident similar to Dulhasti project tunnel occurred in May 2007when routine probing ahead of a 6.8m diameter TBM tunnel in sheared and faulted quartzite at 900m overburden cover punctured a water bearing horizon which resulted in flow of water of over 120 l/s containing about 40% sand and silt debris. The inflow was sudden and occurred at a high pressure which could not be contained. Eventually over 7500m3 of sand and silt debris buried the TBM. The project supposed to be commissioned in 2007 is delayed for about 10 years. National Thermal Power Corporation (NTPC) is constructing the Tapovan-Vishnugad hydroelectric power project (TVHEP) with installed capacity of 520MW (4 x 130MW). The project has HRT of length approximately 12.1 km, of which 8.6 km has been planned to be excavated using a double shield TBM. The remaining 3.5km of the HRT is being excavated by conventional D&B method. During the excavation, the TBM encountered a large fault zone. A major portion of rock detached and dented the shield of the TBM and the TBM got trapped. Subsequently, a bypass tunnel was excavated by conventional D&B to recover the buried TBM. The TBM has been recovered, repaired and again put to use in the same tunnel (Goel et al. 2014).

4.0 Concluding Remarks

Over the past twenty five years blasting which was more or less confined to mineral exploitation in remote locations has evolved and reached the door steps of urban environment. It has become an integral part of any development activity. The technological developments in drilling, explosives and initiations systems assisted with instrumentation and computer aided blast designs have made blasting a safe, economical and rapid means of rock excavation. The varied case studies discussed and the measurements carried out with the latest instruments show that, India too caught up with the global trends and the blasting researchers in India have placed on par with their international counter parts. FRAGBLAST 10 International Conference which was held during November 2012 for the 1st time in India (being conducted over last 40 years once in every four years) stands as a testimony to the contribution of the India blasting researchers to global advancement.

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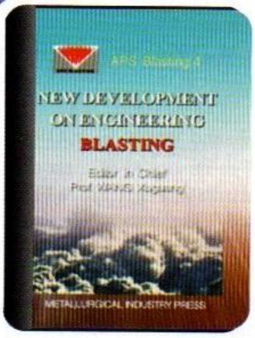
TECHNOLOGY ABSTRACTS



The 4th Asia-Pacific Symposium on Blasting Techniques (APS BLASTING 4) and 8th International Conference on Physical Problems of Rock Destruction (ICPPRD 8), organized by China Society of Engineering Blasting and co-organized by Shenzhen Society of Engineering Blasting, were held on November 17-21, 2014 in Shenzhen, China.

We are grateful to Prof. Wang Xuguang, President, China Society of Engineering Blasting for graciously granting permission to publish selected abstracts from the proceedings of APS BLASTING 4, communicated to Dr. Shushil Bhandari, Member, Advisory Board, Visfotak Journal, vide e-mail dated Jan 20, 2015.

-Editor

I. Preface

More than 180 delegates from Russia, Australia, Canada, Japan, Korea, India, Mongolia, Kazakhstan, Singapore and China participated in it. The Symposium provided an opportunity for experts, scholars, as well as entrepreneurs throughout the Asia-Pacific region, Russia and the Commonwealth of the Independent States to exchange the academic and technical achievements in engineering blasting, industrial explosives and other related fields.

The proceedings were published before the conference. Proceedings contain 91 papers. 37 papers were presented at the conference in 8 sessions. Papers reflect both blasting practices and explosives industry practices used in the major national construction projects. Many case studies presented showed technical innovations used in construction projects and mines. Methods of environmental overcoming constraints were given. There are theoretical and experimental work in some Asia-Pacific countries blasting practices and experiences gained in recent years. The Symposium showcased many important developments taking place in blasting research, design, construction and techniques.

Highlight of the conference was presentations with respect to basic mechanism of blasting fracture and fragmentation using advanced computational and experimental techniques; environmental compliance in respect to ground and air vibration and flyrock and use of harmonics in understanding blasting vibration anomalies. Many papers were presented about practical aspects of large infrastructure construction and application in mines and building demolition.

Dr. Sushil Bhandari and Prof. Debasis Deb were the delegates from India participating in the symposium.

II. Selected Abstracts from the Proceedings of the Conference

Dynamic Failure Mechanism of Rock Mass using Smoothed Particle Hydrodynamics

Ranjan Pramanikand and Debasis Deb

(Department of Mining Engineering, Indian Institute of Technology Kharagpur-721302, India.)

Email: deb.kgp@gmail.com (D. Deb)

Abstract

The paper presents a numerical procedure based on SPH framework to analyze the fracture and fragmentation process of rock medium under dynamic stress wave followed by gas expansion. To analyze the dynamic fracture mechanism related to blast-induced shock wave and gas expansion, a rectangular rock mass containing multiple blast holes were numerically blasted in the proposed SPH framework. The damage pattern around the boreholes and formations are mainly generated due to tensile cracksand are simulated using the developed numerical tool. It is found that the developed procedure has the potential to provide valuable information to understand the physical phenomena those occur in the failure process of rock mass under blast induced dynamic loads.

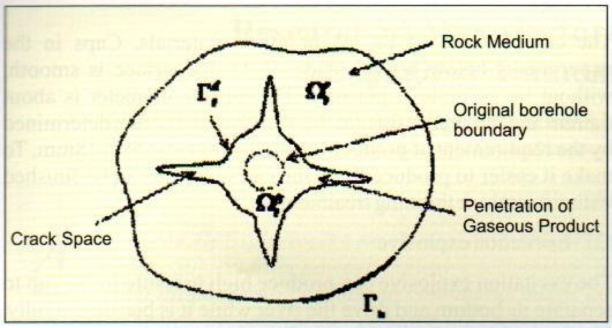


Figure 1 - Schematic of the domains occupied by gas and rock in rock blasting phenomenon

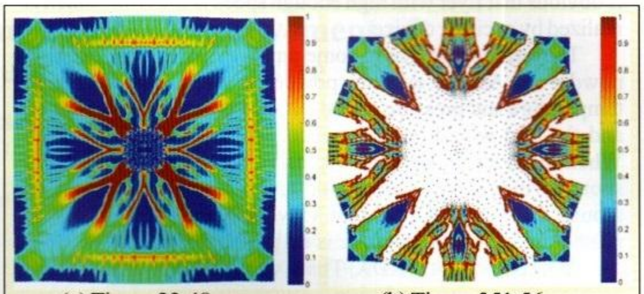


Figure 2 - Accumulation of damage in the rock medium at two different time step

Research on Non-primary Explosive Slapper Detonator System

Shen Zhao-wu and Ma Hong-hao
Modern Mechanics Department, University of Science and Technology of China, Hefei, Anhui, 230027

Chen Zhi-jun[2]
An-hui Lei Ming Hong Xing Chemical Co. LTD, Hefei, Anhui, 231135

Abstract

After many year of hard work non-primary explosive slapper detonator has been manufactured inland. In this article many points of the slapper detonator have been systematically introduced, such as development, features, performance, advantage compared with primary explosive detonator. Basing on non-primary slapper detonator linear delay technique and green detonator idea have been brought in, which may be give some help for innovation in explosive materials.

The non-primary explosive slapper detonator (NESD for short) is invented by Prof. Shen Zhao-wu in USTC. With more than twenty years development this technique has been accepted and manufactured inland, which is to solve safety problem caused by primary explosive detonator. Referring traditional slapper detonator with electrical exploding foil in, the core part "exciting device" has been designed. This article describes the NESD's development process, technique feature, performance by test in detail. In addition the linear delay technique and green detonator idea have been introduced.

NESD TECHNIQUE

Theoretical Foundation

Traditional slapper detonator exploded by flying foil gave the inspiration, which was invented by J.R. Strond in the 1950s. The principles are as follows. Firstly when thousands of ampere current is passing through thin metallic conductor, the conductor would be gasified rapidly and produce plasma with high temperature and high pressure, which would drive the flyer. Secondly Walker and Wasley[1] proposed exploding criteria of heterogeneous explosives:

$$p^2 r = \text{Constant}$$

This criteria shows that whether or not the explosive is exploded is decided by two factors, pressure P and duration time τ. Although this detonator is safe and pollution-free because of non-primary explosive, it needs very strong current with steep-sided pulse, whose initiation system is so huge to be used[2]. The traditional slapper detonator is not suitable for civil use, but it inspired researchers to make improvement on civil detonator.

Other studies[3] have shown that exploding product of PETN ($P^2.\tau$) varies with density, shown in Fig. 1. The slapper driven by explosive could be so fast to firing explosive by impact, implying that detonator could be exploded by fast flyer[4]. This guides the research[5-12].

Table 1 - Critical initiation condition of PETN

Density (Kg/m^3)	Critical initiation pressure (Pa)	Exploding product (Pa^2s)	Critical exploding energy (J/m^2)	Critical exploding velocity of particle (m/s)
$1.60x10^3$	$9.1x10^8$	$125x10^{10}$	$16.4x10^4$	300
$1.40x10^3$	$2.5x10^8$	$41x10^{10}$	/	300
$1.00x10^3$	/	$5x10^{10}$	$8.4x10^4$	/

Design Idea

The slapper detonator is exploded by impact of fast flyer on main explosive. According to exploding criteria of heterogeneous explosives we know that if the impact energy is larger than the critical exploding energy, the detonator would be exploded. So it is obvious that flyer with high enough speed is the crux, which is realized by exciting device.

The exciting device is some small cylinder with exciting powder in. As the exciting powder is fired, gas with high temperature and pressure would cut the bottom part of cylinder, and the part would be accelerated, which is called the flyer. When the flyer impacts the explosive below the cylinder, hot spots developed by compression and pressure, and explosive around the spots is ignited first. Obviously the exciting powder provides the energy, but there is no primary explosive because the main component is RDX. That's why NESD could avoid the problems of primary explosive.

At present kinds of NESD include instantaneous/delay electric detonator, instantaneous/delay nonel detonator. Structure of delay NESD is sketched in Fig. 2.

Structure

There are three components of NESD: ignition part, exciting device, main explosive. Ignition part is used to transport ignition signal from outside to inside, generally ignition charge or nonel. Main explosive is the same as that in primary explosive detonator. These components in primary explosive detonator could be used in NESD directly. The difference is initiation part, one containing primary explosive, the other containing exciting powder without primary explosive.

Exciting device[9]:

The purpose of the exciting device is to produce flyer with high velocity. The components of the exciting device are cap and excitation explosive (in Fig.3). The cap is a thin shell cylinder with top open. The cap is fixed in the detonator shell by bayonet. The density of the excitation explosive in the cap is 0.5-2.5g/cm3, and the height is 0.5-2 times the external diameter of the cap.

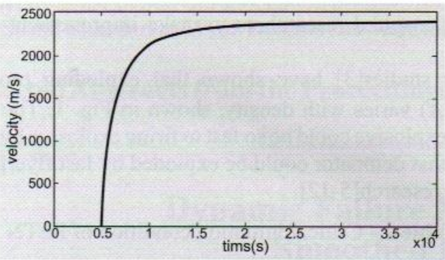


Figure 1 - Velocity curve of flyer (explosive: RDX,1.6g/cm^3,Φ20mm×40mm;flyer:steel, Φ20mm×4mm)

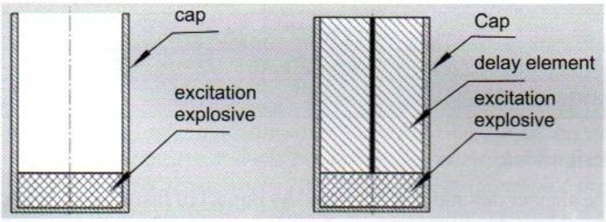


Figure 3 - Sketch map of excitation setting: left one for instantaneous and right one for delay

(1). Cap

The cap is made of Fe, Al or other materials. Caps in the experiments below are all made of Al. Its surface is smooth, without rip or pinhole porosity. The outside diameter is about 6.8mm and the shell is 0.5mm thick. Its height is often determined by the requirement of production, usually not less than 18mm. To make it easier to produce flyer, the cap's bottom can be finished with rift circle or thinning treatment.

(2). Excitation explosive

The excitation explosive can produce high pressure in the cap to separate its bottom and drive the flyer while it is burning rapidly. The excitation explosive is made from pure substance or mixture of RDX, HMX, TNT, PETN, etc. Comparatively the granulated RDX is better to be excitation explosive.

(3). Excitation explosive design[13]

Excitation setting is the key component of NESD, and the excitation explosive is the most important element of the setting. So far RDX and PETN have been proved to be suitable for the excitation explosive. But the properties are different. The thermal stability of pure RDX is better than that of PETN[14,15]. The thermal explosion critical temperature of PETN in 1.74g/cm^3 is 197C, which of RDX in 1.72g/cm^3 is 214C. Cuneiform experiment[3] shows that in the same situation PETN is more sensitive to shock wave than RDX. Because the principle of firing excitation explosive in electric detonator is different from that in non-electric detonator, PETN and RDX used as excitation explosive act dissimilarly. It is proved that granulated RDX is more stable and reliable than PETN[16]. Except special explanation, granulated RDX is used as excitation explosive in this article.

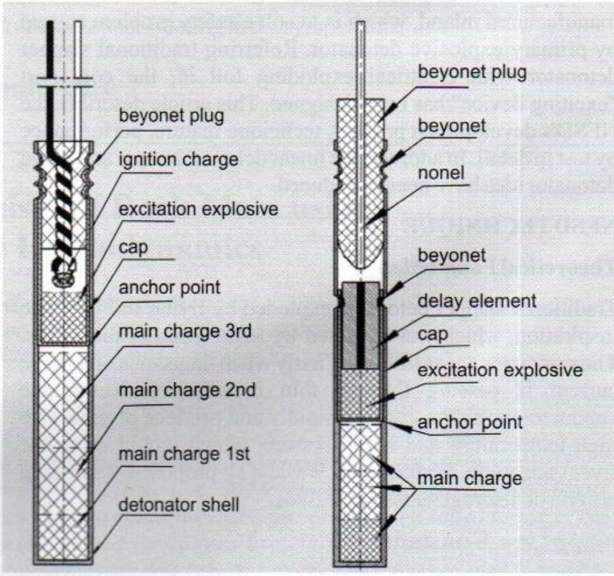


Figure 2 - NESD: left one is electric kind and right one is nonel kind

Research of Manufacturing Process Improvement of Expanded Ammonium Nitrate Explosive

ZhengBingxu, GanDehuai, Song Jinquan and Li Zhanjun
Guangdong HandarBlasting CO,LD, Guangzhou,510623,China

Abstract

As Expanded AN Explosive is a new type of No Ladder Powder Explosive, it gets a wide range of application and development in China. Subject from powder explosive technology, it is based on the research of explosive theory. We put forward the thought that oil phase water phase to continuous mixed continuous puffed crystalline powder, we studied a new production process. The new process further enhance the technology of Expanded AN explosive and simplify the production line greatly, reduce the storage quantity of production line, improve the comprehensive performance of explosive and will have a wide range of significance to develop.

The Comparison of the Commercial Explosives in United States to that in China and Discussion on Development of Chinese Commercial Explosives

Yan Shilong, Guo Ziru, Wu Hongbo and Wang Quan
Anhui University of Sci. & Tech., Huai Nan, Anhui, China

Shen Zhaowu
University of Sci. & Tech. of China, Hefei, Anhui,China

Abstract

The annual consumption, species changes and the application of commercial explosives in United States are presented and analyzed. Based on these analyses, the development trend of commercial explosives in China is discussed and suggested.

Table 1 - Annual consumption, species changes and use fields of commercial explosive in United States from 1993 to 2012

Total consumption and main species percentage (%)				Use fields percentage (%)				
Total consumption (thousand tons)	Blasting agents and ammonium nitrate	Permissible explosive	Otherhigh explosive	Coal	Construction works	Metal ore	Quarrying and non-metal minerals	Others
1880	98.05	0.23	1.72	66	7.23	11.12	12.93	2.76
2320	98.39	0.16	1.45	66	7.24	10.52	13.02	2.84
2280	98.25	0.15	1.60	66	7.23	10.96	13.51	2.51
2240	98.47	0.11	1.42	65	7.14	10.67	13.84	3.17
2670	98.81	0.09	1.10	66	7.23	10.34	13.82	3.07
2910	98.87	0.09	1.04	67	7.15	9.45	14.16	2.57
2120	98.45	0.08	1.47	67	7.41	9.58	13.73	2.77
2570	98.62	0.06	1.32	67	7.55	9.18	13.50	2.84
2380	98.49	0.07	1.44	68	7.52	7.77	13.36	2.86
2510	98.43	0.05	1.52	69	7.53	7.77	13.35	2.83
2290	98.40	0.05	1.55	68	7.86	7.16	14.10	2.76
2520	98.31	0.04	1.65	66	10.32	7.10	14.33	2.38
3200	98.96	0.04	1.00	65	11.00	7.41	14.00	2.28
3160	98.78	0.04	1.18	66	11.58	7.50	12.75	2.03
3150	98.69	0.03	1.28	66	11.59	7.52	11.74	2.44
3420	98.83	0.04	1.05	70	10.94	8.04	10.08	2.25
2270	98.69	0.07	1.04	70	10.35	7.75	9.21	2.51
2680	98.88	0.04	0.84	71	9.18	8.43	9.40	2.51
3000	99.33	0.03	0.73	71	8.83	8.60	9.30	2.50
3380	99.11	0.04	0.93	68	10.38	8.70	10.27	2.60

Table 2 - The total output of commercial explosives and the species changes in China from 2002 to 2008

Years	Total output (million tons)	The species distribution					
		Nitroglycerine explosives (%)	TNT explosive (%)	Water-gel explosives (%)	Ammonium oil explosive (%)	Emulsion explosives (%)	Other explosives (%)
2002	1.56	0.43	52.33	1.26	20.94	25.06	0.39
2004	2.16	0.31	41.85	1.13	24.35	32.28	0.38
2006	2.62	0.08	28.47	1.31	27.87	41.88	0.26
2007	2.86	0.07	10.01	1.45	38.05	46.45	3.99
2008	2.90	0.06	0.19	1.40	44.22	50.06	4.07

Table 3 - The total output of commercial explosives, the species changes and the application fields in China from 2009 to 2013

Year	Total output (million tons)	The species distribution(%)						The distribution of application fields (%)				
		Bulk emulsions	Bulk ANFO	Water-gel explosives	Powder emulsion, expanded AN etc.	Emulsions	Other	Coal mining	Metal mining	Non-metal mining	Construction	Other
2009	2.96	6.1	10.4	1.3	39.0	40.2	1.0	29.3	22.3	23.5	18.4	6.5
2010	3.52	5.8	10.3	1.2	38.7	42.9	1.1	-	-	-	-	-
2011	4.07	6.4	10.6	1.0	36.5	43.6	2.0	26.6	24.5	26	11.0	11.9
2012	4.19	7.2	12.6	1.0	32.1	43.8	3.3	29.4	23.7	24.9	8.8	13.2
2013	4.37	6.4	15	1.1	27.9	46.3	3.3	31.0	26.0	25.0	9.0	9.0

Table 4 - The package specification of commercial explosives in china in recent years

Year or species	Package diameter< 40mm(%)			Package diameter>40mm(%)			Bag package			On-mixed		
Year	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
Total explosives	42	37.5	33	18.1	20.1	23	22.1	22.6	24	17.8	19.8	21
Emulsions	58.3	54.4	/	37.0	40.7	/	4.7	4.8	/	0.0	0.0	/
Water gel	71.5	66.9	/	27.1	33.1	/	0.5	0.0	/	0.0	0.0	/
Expanded AN	47.4	44.5	/	2.5	1.7	/	50.1	53.8	/	0.0	0.0	/
Modified ANFO	30.8	24.9	/	6.3	9.4	/	63.0	65.7	/	0.0	0.0	/
Powder emulsion	42.9	38	/	3.6	3.5	/	53.5	58.5	/	0.0	0.0	/

Development trend of China's Commercial Explosives

1) Be optimistic to China's demand for total consumption of commercial explosives in the coming decades

The United States is the most developed country in the world today. Its commercial explosives mainly uses in mining and the annual consumption reaches to 3 million tons today. China is still a developing country and will inevitably consume various resources for its industrialization and infrastructure construction in future. Thus it will still consume a large mount of explosives. It is expected that China will have great demand of commercial explosives in the coming decades or even a longer period.

2) Vigorous promotion of the development of safer, cap-insensitive, simple-manufactured explosives

From the view point of cleaning and environmental protection, species and type of China's commercial explosives is similar to that of the United States, which is consistent with the overall trends of industrial explosives technology development. However, as to the open-pit deep hole blasting, the explosive species does not match with blasting technology in China and not achieve the safer and more efficient in technology and economy.

As the improvement of productivity, the deep hole blasting technology has been widely and consciously accepted by society currently. Meanwhile, it has been widely used in basic engineering constructions of road, water hydropower etc. and quarrying, mining etc.. Therefore, it should devote major efforts to developing safer, cap-insensitive, simple-manufactured explosives and promoting onsite mixed and simple-manufactured explosives, such ANFO in various density, cap-insensitive slurry and emulsion blasting agents, and their mixtures with ANFO (Heavy ANFO). Currently, it is not economic and safe, or even not necessary that emulsions, powdery emulsion, the modified ammonium nitrate fuel oil explosives with large diameter or bagged package and more over with cap-sensitive are used in deep-hole blasting produced by many factories.

3) Developing coal-mining permissible explosives with the property of safer level against methane-air ignition and more reliable detonation at same times

Coal-mining in the United States is a major contributor of explosive consumption, but most of its coal mines is open-pit. Thus, the amount of permissible explosives is few. This situation means no one shows any interest in technology improvements, performance testing and government regulation for coal mine permissible explosives in the United States. For example, the test gallery and relative instruments for coal mine permissible explosives could not run normally. An explosion event in 2008 urged Institute of Manufacturers of Explosives to ask the United States Council to pay attention and fund for the permissible explosives. In China, most coal mines are underground and under gassy condition while coal is primary energy consumption in China. In order to ensure the blasting safety of coal mining, it should not weaken the technologic improvements, performance testing and government regulation for permissible explosives. Blasting operation in coal mine requires that the permissible explosives should be cap-sensitive. Meanwhile, in order to prevent blast to cause the ignition of methane and coal dust, the energy content of permissible explosives must be controlled and chemical inhibitors are often needed to add to the permissible explosive compositions. Meanwhile, rock-breaking capacity of the permissibles also should be ensured. Based on the current situation of China's coal mine permissible explosives and the blasting practice of underground coal-mining, coal mine permissible explosives of water-gel type are the most safe against the ignition of methane and coal dust, and the most reliable in detonation, especially for the high-safe level permissible explosives. So, it is suggested that the high-safe level permissible explosives should be water-gel type explosives.

4) The enhancement for production concentration of commercial explosives

The numbers of manufacturer of China's commercial explosives have fallen significantly for many years, and the production scale and concentration level have increased. However, compared with the United States, there are still more manufacturers of China's commercial explosives. In order to improve safety and efficiency, it is the instinctive needs for enterprises and society to enhance the production concentration.

Production of Nitroester-based Explosives in Russia

A.S. Zharkov, E.A. Petrov, N.E. Dochilov and R.N. Piterkin
JSC Federal Research and Production Center "ALTAI".

Abstract

FR & PC "ALTAI" is one of the largest Russian scientific centers developing receipts and technologies of industrial explosives in Russia. In 2013, it is 15 years since FR & PC "ALTAI" launched the production of high-safety nitroester explosives, which are applied at coal mines especially dangerous by the concentration of combustible gas and coal dust. Production of high-safety explosives is distinguished by a high degree of explosion safety and survivability of technological operations. Closed water and acid-rotation, purification of rinsing water, catch of acid vapor and solid release by means of modern methods provide ecological purity at all stages of the process. The technological process is almost completely automated. Phase control of nitroesters production, the process of mixing and patronizing of explosives is performed remotely with the coordination at central control station. Due to its flexibility and adjustability the technological complex is universal and able to produce all types of high-safety explosives.

Table 1 - Standard nitroester explosives

Parameters	Blasting gelatin	62% dynamite	Detonite M	Uglenite E-6	Uglenite 12TsB	Ionite
Density, g/cm^3	1.55	1.4…1.5	0.95-1.2	1.1-1.2	1.0-1.3	1.0-1.2
Velocity of detonation, km/s	7.8	6.5	4.2-5.0	1.9-2.2	1.9-2.0	1.6-1.8
Exothermicity of reaction, kJ/kg	6530	5333	5800	2680	2300	1930
Performance, cm^3	595	360-400	460-500	130-170	95-120	95-125
Brisance, mm	24	15-18	18-22	7-11	5-7	5-6

Table 2 - High-safety explosives (class 5)

Parameters	E-6 (mod)	S	P	M	13P
Exothermicity of reaction, kcal/kg	640	700	780	707	630
Gas volume, l/kg	560	600	600	685	665
Velocity of detonation, km/s:					
of an open charge	2.3	1.8	2.3	1.8	2.0
of a cased charge	2.6	2.3	2.8	2.5	2.4
Sensitivity:					
to shock, %	68	30	70	62	60
to friction, kgf/cm^2	2300	4500	2500	5400	2400
Mass of a charge limit, g	250	300	200	350	250
Efficiency, mm	6.8	7.8	8.3	7.6	6.8

Properties of Emulsion Matrices of Explosives Based on the Best Russian, Kazakh and Chinese Emulsifiers

E.A. Petrov
Russia, Polzunov's Altay State Technical University, Naukograd Biysk,Russia, Federal Research and Production Center, ALTAI, Naukograd Biysk

P.I. Savin
Russia, Federal Research and Production Center, ALTAI, Naukograd Biysk

P.G. Tambiev
Kazakhstan, Research and Production Enterprise, INTERRIN" Almaty

Abstract

Strain-stress properties of emulsion matrix (EM) poremit-type, obtained on the best emulsifiers of Russian, Kazakh and Chinese productions were investigated in this study. Comparative results are given here concerning emulsifying efficiency of the following emulsifiers: polymeric grade REM (Russia), pigmental grade "P" (Kazakhstan), polymeric grade SPAN-80 (China). The following parameters were estimated: microstructure, electric capacity, viability, thermal stability. Microstructure was determined by the method of optical microscopy with zooming in 400 times; viability was estimated according to electric capacity changing; thermal stability was measured by the method of differential thermo-gravimetric analysis; measurement of electric capacity was room-temperature. Studies concerning emulsifying efficiency showed that under equal experiment conditions more higher stress-strain properties and EM quality were obtained with REM. To achieve the same results of EM with SPAN and P, it is necessary to increase the content of emulsifier or burning phase in composition.

The following grades of emulsifiers were used: - polymeric grade REM-2, Spec. (ТУ) 7511903-631-93 (Russia);- pigmental grade "P" ST TOO 38441379-01-2006 (Kazakhstan);- polymeric grade SPAN-80 (China).The following parameters were estimated:- microstructure by the method of optical microscopy with zooming in 400 times;- electric capacity by the method of GosNII "Kristall", measured at room temperature [4];- viability according to changing of electric capacity at room temperature after circular loadings "hot-cold" [4];- thermal stability by the method of differential thermo-gravimetric analysis on thermal analyze DTG-60 by "SHUMADZU".Emulsion matrix was prepared in the laboratory mixer at temperature of 80 °C with the use of double-level agitator turbine type. The rotation speed was 3000 rpm. EM compositions and the results of studies on electric capacity are given in Table 1. Marking of compositions is given in accordance with the grade of applied emulsifier.

Table 1 - Compositions and electric capacity

Component content, %	SPAN	SPANV	REM	P	PV	$P_{10.5}$	$PV_{10.5}$
Ammonium nitrate	79	79	79	79	79	77	76.5
Water	14	13.5	14	14	13.5	12,5	12.5
Wax	-	0.5	-	-	0.5	-	0.5
Emulsifier	1.5	1.5	1.5	1.5	1.5	2.25	2.25
Dis. fuel	5.5	5.5	5.5	5.5	5.5	8.25	8.25
Electric capacity, πF	280	144	142	280	180	150	127

Figure 1 - SPAN microstructure

Figure 2 - REM microstructure

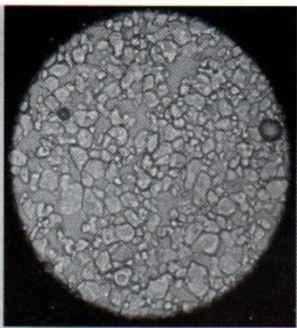


Figure 3 - P microstructure

Figure 4 - PV microstructure

State-of-the art Review of R&D on the Blast Vibration at KIGAM

Chang-Ha Ryu, Byung-Hee Choi, Hyung-Su Jang and Myoung-Soo Kang
Geologic Environment Division, Korea Institute of Geoscience & Mineral Resources (KIGAM)
124 Gwahang-no, Yuseong-gu, Daejeon 305-350, KOREA

Abstract

Explosive blasting is very useful tool used for breaking rock in mining, quarrying and civil engineering constructions. However, the use of explosives always produces undesirable environmental impact due to the ground vibration, air-overpressure and flyrocks. Blast vibration may cause damage to adjacent structures, and has been a serious environmental issue. A series of R&D works on the blasting area have been done at Korea Institute of Geoscience & Mineral Resources(KIGAM) for past 20 years. A new method was developed to predict the ground vibration for the evaluation of safety of blast design in its relation to the generation of ground motion. It is based on the non-parametric source identification method, and provides the information on the history of ground motion as well as peak level of vibration. Parameter study was performed on time-domain using some commercial software like LS-DYNA, MIDAS, etc. Sensitivity analysis was carried out to set up the guidelines for the preparation of the basic input parameters in numerical modeling of blasting problems. In order to establish the National Standard for safe blasting work, allowable ground vibration level was suggested. Extensive field measurements have been done at various mining and construction sites to investigate the characteristics of blast-induced ground motion and structural response. In order to control the ground vibration more effectively, a new fracturing device was developed, which is applicable to the site where ground vibration has come to the front. Software for blast design was developed too. This paper summarizes the results of what have been done at KIGAM, including some current R&D work.

Safety Limit of Vibration Level

Allowable level

A safety limit of ground vibration in Korea is provided by the Environmental law only for the pleasant life of residents as shown in Table 1. A vibration level which is compensated for human response is used as an indicator. The law is applied to the ground vibration generated from the general life works including the civil and construction work, plant operation, mining work, etc. The vibration levels in Table 1 is those for blasting work, which are 10 dB bigger than those for other general works, by considering the transient characteristics of blasting and working time.

Table 1 - A safety limit of ground vibration by Korea Environmental law

Area	Time zone (06:00-22:00)
Residential area, green belt area, recreational area, environmental preservation area, school zone, area of hospital and public library	Less than 75 dB(V)*
Other area	Less than 80 dB(V)

* dB(V): Vibration level in vertical direction
$dB(V) = 20 \log (A/Ao)$, dB
$Ao = 2 \times 10^{-5} \times f^{1/2}$ for $1Hz \leq f \leq 4Hz$; $Ao = 10^{-5}$ for $4Hz \leq f \leq 8Hz$;
$Ao = 0.125 \times 10^{-5} \times f$ for $8Hz \leq f \leq 90Hz$
where A = root mean square value of acceleration, m/s^2; Ao = reference acceleration; f = frequency.

Table 2 shows a safety limit for structures suggested in early 1980's for urbane subway construction works in densely populated capital city. It had been used as a guideline of allowable ground vibration level for blasting works for quite a long time in Korea.

Table 2 - Allowable vibration level suggested for urbane subway construction works

Structure type	Allowable limit, mm/s
Antique, computer facility	2
Residential structure, apartment building	5
Commercial building	10
Factory, reinforced concrete building	10~40

The former U.S. Bureau of Mines recommended a safe particle velocity maximum of 5 cm/s for residential structures for frequencies above 40 Hz (Siskind et al., 1980). The regulation of the Office of Surface Mine specifies that the maximum ground vibration shall not exceed 0.75 - 1.25 in/s (1.9 - 3.2 cm/s) at the location of any dwelling, depending on the distance from blasting site (30 CFR part 175). Most US States adopt the blast vibration level of 1 - 1.2 cm/s as an allowable level for residential structure. The German vibration standard, which is known to be very conservative, gives varying levels of 0.5 - 2 cm/s for residential structures depending on the frequencies (DIN 4150, 1986). Some other countries have their own National Standard such as Swiss Norm 640 312a, British Standard BS7385, Australian Standard AS 2187.2, China GB6722-2003, etc. A variety of National vibration limits are listed elsewhere (Skipp, 1977).

Visfotak EXPLOSIVES SAFETY & TECHNOLOGY SOCIETY
TECHNOLOGY ABSTRACTS

Blasting Harmonics

Adrian J. Moore and Alan B. Richards
Terrock Consulting Engineers, Australia

Abstract

Blast holes fired in a pattern with a constant initiation delay create a frequency in the ground vibration similar to that from a percussion instrument, such as a drum, in the air. A constant firing delay generates a prime or forcing frequency into the ground motion. The forcing frequency may then be modified by ground transmission characteristics into sub harmonics or super harmonics of the forcing frequency. The moving vibration source between blast holes creates a frequency shift because of a Doppler Effect. Other wave interactions may form beats. The effects are exacerbated by the accurate firing times of electronic detonators

This paper uses observations of wavetraces and frequency spectral analysis to demonstrate:

- *Doppler Effect and frequency ellipsoids;*
- *Sub (and sub-sub) harmonics of the forcing frequency;*
- *Super harmonics of the forcing frequency;*
- *Beat formation that may double or triple PPV levels;*
- *The effect that some geological conditions have on wave shapes.*

An understanding of the science involved has a practical application that has been successfully applied to initiation timings to reduce Peak Particle Velocity and adverse human and structure response from blasting operations.

Conclusions

1. The ground vibration resulting from a blast is often influenced by factors other than charge mass and distance.
2. Controlling ground vibration by charge mass reduction alone has its limitations a 50% charge mass reduction reduces the PPV by about 40% without affecting the other contributing factors.
3. The initiation sequence produces forcing frequencies which may then be modified by
   - Doppler Effect;
   - Directional Frequency variations;
   - Sub harmonic splits;
   - Super harmonic development.
4. Beats are formed when two or more generated frequencies are closely aligned, e.g. 16.8 hz and 15.8 hz.
5. The beat frequency is the difference between the two frequencies

   E.g. 16.8 hz and 15.8 hz the beat frequency is 1 hz.
6. The beat wavelength is 1000 ÷ beat frequency = 1 second long.
7. Beats consisting of 2 frequencies may double the PPV in the channel affected and three frequencies may treble the PPV.
8. To reduce the PPV by preventing beat formation, first they have to be recognised and then the initiation sequence and direction of firing modified.
9. Forensic wave trace examination to identify the causes of the peak PPV measured is an essential part of the blasting review process, especially if the PPV levels are approaching regulatory limits.
10. The geology between the blast and a surface receptor can influence to wave shape, the PPV, the frequency spectrum and the vibration duration. This can also be evidenced by detailed forensic examination of the wavetrace.
11. In situations where the geology is resulting in harmonious wavetraces, experimenting with variations in control timing to break up the forcing frequencies may be beneficial.

PATENTS

Recent Patents of Interest

United States Patent **20140367604**
Alexander, at al. **December 18, 2014**

Hot Hole Charge System

Abstract

An apparatus, method and insulation medium for inserting and insulating a charge medium within a borehole includes a charge tube comprised of an elongate tube having a length and diameter sufficient for containing a desired quantity of a charge medium. A charge medium in a pumpable form is provided for substantially filling the charge tube. An insulation medium in a pumpable form is provided for substantially encapsulating the charge tube and substantially filling an annular space between the charge tube and the borehole for insulating the charge tube from a downhole environment in which the charge tube is to be inserted. A detonator is inserted within the charge medium proximate a distal end of the charge tube and a charge cable extends from the detonator through the charge tube and exits from the charge tube.

Summary of the Invention

[0017] Accordingly, the present invention relates to systems, methods and compositions used with commercial explosive materials and systems and methods for delivering such commercial explosive materials into a borehole. The systems, methods and compositions of the present invention can be used with any commercial explosive material in a pumpable form for delivery into a borehole, whether by pneumatic extrusion, compressed air, plunger systems, worm gear or screw systems or other methods known in the art. Such pumpable forms of explosives may include gels, emulsions or slurries.

Inventors : **Alexander; Brent Dee,** (American Fork, US)
Assignee : -

United States Patent **20150033969**
Gore, et al. **February 5, 2015**

Modified Blasting Agent

Abstract

The present invention relates generally to an explosive composition comprising an aqueous emulsion of: an oxidizer component, a hydrocarbon fuel component containing emulsifier, and a bulking agent being a fuel-type waste material in a solid particulate form substantially lacking rough surfaces and sharp edges. Preferably the composition is of an ammonium nitrate based emulsion and a pelletised bulking agent. It also involves a method of providing an explosive composition to a blast site using a conventional mobile processing unit (MPU), being a truck having separate compartments adapted for holding fuel oil, dry ammonium nitrate prill, and ammonium nitrate based emulsion, where a compartment instead holds particulate waste material. It also concerns a method of blasting soft and wet ground, which comprises injecting into one or more blast holes in the soft and wet ground a sufficient quantity of the composition, and then setting off the composition.

Summary of the Invention

[0009] According to one aspect of the invention there is provided an explosive composition comprising an aqueous emulsion of: an oxidizer component, a hydrocarbon fuel component containing emulsifier, and fuel-type waste material, as a bulking agent, being in a solid particulate form that substantially lacks rough surfaces and sharp edges sufficiently so as to not promote crystallisation of the emulsion.

Inventors : **Gore; Jeff,** (Mt. Thorley, AU)
Paris; Nathan, (Mt. Thorley, AU)
Assignee : **Dyno Nobel Asia Pacific Pty Limited**

United States Patent **20150003186**
Xue, et al. **January 1, 2015**

Site Vehicle for Mixing and Loading Multiple Kinds of Explosives with Different Detonation Velocities

Abstract

Provided is a site vehicle for mixing and loading multiple kinds of explosives with different detonation velocities. The vehicle contains a double-helix conveying system, a plurality of storage bins (5-8) and multiple sets of pipelines. Emulsified bases, porous granular ammonium nitrate and physical density modifier are stored in the main material storage bins, an adjuvant storage bin is provided with a diesel tank (4, 31), a sensitizing solution tank (40) and a washing water tank (11), and the technical effect that multiple kinds of explosives with different detonation velocities are mixed and loaded can be realized by using the different combinations of the different raw materials of the storage bins and various output pipelines and some baffle plates. The vehicle has the advantages of multiple purposes, capability of producing heavy emulsion explosive, density-modifiable heavy emulsion explosive, low density emulsion explosive, ultra-low density emulsion explosive, heavy ammonium nitrate fuel oil explosive, density-modifiable ammonium nitrate fuel oil explosive, porous granular ammonium nitrate fuel oil explosive, density-modifiable porous granular ammonium nitrate fuel oil explosive, and minor-diameter and long-distance conveying emulsion explosive, and applicability to the needs of various blasting operation environments and loading different kinds of explosives in the same blast hole.

Summary of the Invention

[0009] The invention aims at providing an on-site mixed loading truck for explosives with different detonation velocities. A porous granular emulsion ammonium nitrate fuel oil explosive integrates the advantages of an emulsion explosive and a porous granular ammonium nitrate fuel oil explosive, also overcomes the disadvantages and shortcomings of the existing emulsion explosive; while retaining the good properties of the porous granular ammonium nitrate fuel oil explosive, it also overcomes the defects of poor moisture-proof and water-proof performances of the ammonium nitrate fuel oil explosive, simultaneously overcomes the shortcomings of high density and high unit explosive consumption of the emulsion explosive, and solves predicament of poor density modification performance of the emulsion explosive. The on-site mixed loading truck for the emulsion ammonium nitrate fuel oil explosive of the invention can provide a large range of emulsion explosive density modification and realize the on-site mixed loading truck for explosives with different densities and different detonation velocities.

Inventors: **Xue; Shizhong,** (Weihai, CN)
Assignee: **Qingdao Target Mining Services Co. Ltd.** (Qingdao, Shangdong)

United States Patent **20150013858**
Xue, at al. **January 15, 2015**

Preparation Method of Explosives with Differrnt Densities and Explosives with Different Density

Abstract

Disclosed are explosives, especially a preparation method for explosives of different densities and explosives of different densities. The method adjusts physical density by adding granular form physical density adjusting agent with 0.5-5.0 mm grain diameter and 0.03-0.30 g/cm3 bulk density when preparing explosives. The method can adjust the explosive's density within a large range to produce the explosives with a wide range of detonation velocity to meet different needs for explosive velocity according to different lithology, and simultaneously meet needs for different explosives in the same blasthole.

Summary of the Invention

[0006] The invention aims at overcoming the shortcomings of the prior art as stated above and providing a preparation method of explosives with different densities. A variety of explosives within a relatively wide density range can be prepared through the method.

Inventors: **Xue; Shizhong,** (Weihai, EN)
Assignee: **Qingdao Target Mining Services Co. Ltd.** (Qingdao, Shandong)

SPECIAL REPORT

Safex International

'Safex Incidents Notices' : April, 2014 to March, 2015

Activity	No. of Incidents
1. Commercial Explosives	
• Manufacturing	
▪ Fixed Plants	
HEs/AN	1
BAs	1
Sub total	2
▪ Mobile Bulk Units (MBUs)	-
Sub Total	**2**
• Handling	-
• Storage	-
• Transportation – Vans/Bulk Trucks	3
• Waste / unused explosives disposal etc.	2
• Use of explosives	2
Total	9
2. Pyrotechnics / Propellant / Ammunition	4
Grand Total	**13**

1

1) **INCIDENT TITLE :** 09 Jun 2014: Chile – Fly rock fatality during secondary blasting
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Explosives were not directly involved in the incident
   b) **What happened**: A Maxam employee working on this open pit mine was hit by a rock fragment during a secondary blasting operation.
   c) **Why did it happen theory** :The precise circumstances and cause of the incident is unknown pending the outcome of the investigation which is underway.
   d) **What was the impact** : The employee died as result of the injuries he sustained.
3) **COMMENT**
   a) **Value of incident** : While it can be argued that this is a mining incident, a number of SAFEX members provide an on-site service to their customers as in this case. Therefore, the findings of this investigation may be relevant.
   b) **Observations :** On behalf of SAFEX Members, we extend our heartfelt condolences to the family and friends as well as the management and colleagues of the deceased.

2

1) **INCIDENT TITLE :** 16 April 2014 : USA Deflagration in ammunition plant
2) **INCIDENT OUTLINE**
   a) **What material was involved :**Unknown amount of simple base powder for hunting cartridges.
   b) **What happened**: A deflagration occurred during maintenance operations.
   c) **Why did it happen theory** :The reason for this explosion is unknown and under investigation
   d) **What was the impact** :Four people were injured and taken to hospital where one died shortly afterwards. One is in a critical condition while the other two were not badly injured and were discharged from hospital.
3) **COMMENT**
   a) **Value of incident** : In the absence of any further information, this incident is primarily of statistical value. It underscores the risk associated with maintenance activities in an explosives plant.
   b) **Observations :** We extend heartfelt condolences on behalf of the SAFEX community to the family and friends of the deceased as well as his colleagues and management at Rio Ammunition.

3

1) **INCIDENT TITLE :** 14 Jun 2014 : Chile - Violent decomposition in AN distributor vessel
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Approx. 40 l of ammonium nitrate (AN) solution
   b) **What happened**: While an operator was routinely cleaning the hot concentrated AN solution spraying nozzles on the 10th floor of the AN prilling tower, a violent decomposition of the AN occurred.
   c) **Why did it happen theory** : It is postulated that an accumulation of organic additive inside the piping was dislodged by the flow through it and mixed with the solution. This resulted in the additive content exceeding 4000 ppm which sensitized the AN.
   d) **What was the impact** : The pressure shock wave caused by the decomposition of AN threw the operator to the floor and caused injury to his arms and left eardrum. The AN solution distributor vessel was totally destroyed with minor damage to the roof.
3) **COMMENT**
   a) **Value of incident** : The sensitivity of AN to impurities is highlighted by this incident as is the need for effective routine cleaning procedures. The IR will elaborate on the detail thereof.
   b) **Observations :** None

4

1) **INCIDENT TITLE :** 16 Jun 2014: Austria – NG cartridge explosion on burning ground
2) **INCIDENT OUTLINE**
   a) **What material was involved :** About 30 kg of cartridged dynamite explosive,
   b) **What happened**: Old dynamite cartridges (50 mm returned product manufactured in 1988 with 22 % NG) were burnt at the burning ground. After several rounds of burning, another fire was set up with a single layer of cartridges and fire supporting material (wooden pallet, cardboard, etc.) according to the standard burning procedure. An explosion occurred 15 minutes after the fire was started.
   c) **Why did it happen theory :** The exact reason for the explosion is unknown at this stage. The Abel test result for checking the stability was > 1 hour and the sensitivity to impact (Fall hammer) was determined at 5 J. Despite these results, the dynamite was over aged and NG had started to separate and seep out (the cartridges were treated with sawdust prior to handling). Though the material was laid out in a single layer of cartridges, NG pockets may have formed or become confined in the setup.
   d) **What was the impact :** There were no injuries but the cage that prevents burning debris from being blown towards the surrounding forest was destroyed.
3) **COMMENT**
   a) **Value of incident :** During disposal of explosives by burning there is always the potential for an explosion. Standard procedures need to be reviewed/assessed for the disposal of 'non-standard' (more hazardous) products. The incident also shows the importance of operating burning ground areas remotely with the area cordoned off.
   b) **Observations :** After reviewing the operation, the remaining dynamite was burned in batches of 2 x 10 kg with gaps between the cartridges

5

1) **INCIDENT TITLE :** 19 June 2014: Turkey – Propellant press explosion
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Approximately 1-2 kg. of M7 propellant
   b) **What happened:** A stoppage occurred while pressing the M7 propellant. As three operators went to the press to investigate the reason for the stoppage an explosion occurred.
   c) **Why did it happen theory :** The precise circumstances and cause of the incident are unknown and is under investigation.
   d) **What was the impact :** The 3 workers were injured:
      - One incurred 40% second degree burns;
      - A second 25% third-degree burns; and
      - The third 12% second-degree burns.

      There was no damage to the equipment but one of the walls and the door of the building were totally destroyed
3) **COMMENT**
   a) **Value of incident :** With the limited information available, the incident is primarily of statistical value. However, it does illustrate the increase in risk when an unusual occurrence is encountered as in this case.
   b) **Observations :** None

6

1) **INCIDENT TITLE :** 8 July 2014 : Australia - Propellant ignition in hoist
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Trace quantities of single base propellant
   b) **What happened:** An operator was lowering an empty cut powder buggy to the ground, when multiple flashes or sparks were observed coming from the housing of an air driven chain hoist. After dismantling the hoist, propellant grains were found imbedded in the grease inside the chain drive mechanism.
   c) **Why did it happen theory :** Under investigation
   d) **What was the impact :** There were no injuries or damage.
3) **COMMENT**
   a) **Value of incident :** This incident highlights the importance of maintaining good housekeeping in explosives facilities.
   b) **Observations :** None.

7

1) **INCIDENT TITLE :** 06 Nov 2014: Canada – AN solution truck fire
2) **INCIDENT OUTLINE**
   a) **What material was involved :** As the fire was contained in the tractor section of a tractor-trailer there was no product directly involved. The product being hauled was 40 tonnes of AN solution in a "B" train configuration.
   b) **What happened:** While in transport the tractor caught fire. The driver of the tractor trailer successfully disconnected the trailer containing the AN solution and moved the tractor. The separation between the tractor and the trailer was approximately 17 metres (50ft).

      The highway was closed on either side of the incident, (~1,600m). Residents from the nearby area, (~300 persons) were temporarily relocated. Local emergency services attended the incident and positioned themselves at a safe distance. The progress of the fire was then monitored using an emergency services helicopter.

      Once the fire burnt down, the trailer that was transporting the AN solution was inspected and deemed fit for service. It was relocated to an Orica site for secure storage.
   c) **Why did it happen theory :** The incident is presently under investigation and the exact cause of the fire in the tractor is therefore unknown.
   d) **What was the impact :** There were no injuries. The tractor was the only equipment damaged in this incident.
3) **COMMENT**
   a) **Value of incident :** At this stage the incident is primarily of statistical value. The response appears to have been exemplary which is of value itself.
   b) **Observations :** None.

8

1) **INCIDENT TITLE** :05 Sep 2014: Australia – AN truck explosion

2) **INCIDENT OUTLINE**

a) **What material was involved :** 52.8 tonnes (44 bulk bags each weighing 1.2 tonnes) of TGAN was manufactured in Orica's Gladstone Plant, Queensland. TGAN is an oxidizing agent classified under the United Nations system (Un1942) as a dangerous good of Class 5.1, packing group3.

b) **What happened**: A vehicle consisting of a prime mover, dolly and two trailers in a Type 1 road train was transporting a load of TGAN from Gladstone, Queensland to a mine in South Australia. At about 8:55pm the truck failed to negotiate the bridge at Angellala Creek and came to rest in the dry creek bed adjacent to the road bridge and in the proximity of a rail bridge. The driver was injured and the vehicle caught fire.

Two other truck drivers stopped to assist and the emergency services were called. A small explosion occurred while the responding police and fire crews were tending to the injured driver. They relocated to a position further away from the burning vehicle and a large second explosion occurred. All people at the scene sustained injuries, most of them very serious.

c) **Why did it happen theory** :The incident is presently under investigation and the exact cause is therefore unknown. Ammonium nitrate which is subjected to stimuli capable of causing an explosion can explode when exposed to extreme heat or fire, a combination of heat and pressure, contamination with fuels, organic matter and other chemicals or a combination of any of these.

d) **What was the impact** : Eight people were injured - 7 injuries to persons in close proximity to the seat of the explosion and 1 other person at a different location further from the blast. Four of the injured suffered serious injuries.

The road train, a fire engine and road bridge were destroyed. The other fire engine received serious damage as did the police car and two transport trucks. The rail bridge sustained major structural damage.

A crater of about 12 metres by 8 metres by 6 metres in the creek bed resulted from the explosion.

3) **COMMENT**

a) **Value of incident** : The true value of this incident can only be assessed once the investigation is complete and report issued. However, the incident does illustrate the point that the SAFEX Good Practice Guide (GPG) on "Storage of Solid Technical Grade Ammonium Nitrate" (SAFEX GPG02Rev2.01, p 19) emphasises:

"Fires involving ammonium nitrate (AN) should never be fought.
If the fire involves AN, the facility (area) must be evacuated"

Evacuation distances must be specified in the applicable Emergency Procedures.

b) **Observations :** None

9

1) **INCIDENT TITLE** : 29 October 2014 : Indonesia Unplanned Detonation of a blast hole

2) **INCIDENT OUTLINE**

a) **What material was involved :** 80 Kg of emulsion based bulk explosive product at the blast hole which has been stemmed and tied in.

b) **What happened**: One blast hole detonated prematurely approximately 47 minutes after charging. The hole was 4t meters deep, and had been loaded with 80kgs bulk product (70% emulsion/30% Ammonium Nitrate (AN) dry addition) into a plastic liner due to ground cavities. It was located at the free face in the northern part of the shot. There were 373 holes at the shot.

Detonation resulted in rock breakage and black smoke release, the hole initiated in full order. Diameter of crater was approximately 2 meters, fly rock distributed to radius approximately 20 meters. The nearest person was 70 meters from the hole that detonated. No one was injured.

c) **Why did it happen theory** :The event is believed to have been caused by hot and/or reactive ground coming into contact with the explosive. It is not known whether the detonator, booster, or bulk explosive was the first to react.

The pattern was drilled 4 days before the incident. It is possible that the drilling process led to the exposure of oxidisable sulphur and organic matter to air, allowing the ground heating process to begin. Liner was used in the blast hole due to ground cavities. The blast hole was at the free face, hence there may have been some incoming air, which may have assisted any oxidation reaction to proceed.

The hole showed signs of having an elevated temperature prior to loading. A temperature measurement was undertaken prior to deeming the hole to be safe to load, however, the actual temperature may not have been determined accurately due to incorrect measurement process, including using a measurement device inappropriate for the task.

Subsequent laboratory testing revealed that the ground around the location of the blast was highly reactive with AN. Reactivity testing resulted in 6 out of 13 samples reacting with AN at 550C, some within a one hour time frame.

d) **What was the impact** : No one was injured.

The hole initiated in full order. Diameter of crater was approximately 2 meters, fly rock distributed to radius 20 meters

3) **COMMENT**

a) **Value of incident** : The Incident emphasises the importance of the implementation of controls set out in the AEISG Code of Practice Elevated Temperature and Reactive Ground.

b) **Observations :** None

10

1) **INCIDENT TITLE :** 24 Nov 2014: Saudi Arabia – Overturned ANFO truck
2) **INCIDENT OUTLINE**
   a) **What material was involved :** 18 t of ANFO
   b) **What happened**: A truck loaded with ANFO ran into the left hand crash barrier next to the road, overturned and skidded on its left side for 120 m. The authorities were notified and the police were on the scene in a short time.
   c) **Why did it happen theory** : The driver was driving too fast when he approached a sharp bend in the road and lost control due to heavy rain.
   d) **What was the impact** : The driver sustained minor injuries and the truck was slightly damaged. The ANFO bags were transferred to another truck and conveyed to the planned destination.
3) **COMMENT**
   a) **Value of incident** : Besides its statistical value, this incident emphasizes the need for drivers to adapt their speed to the prevailing road and weather conditions.
   b) **Observations :** None

11

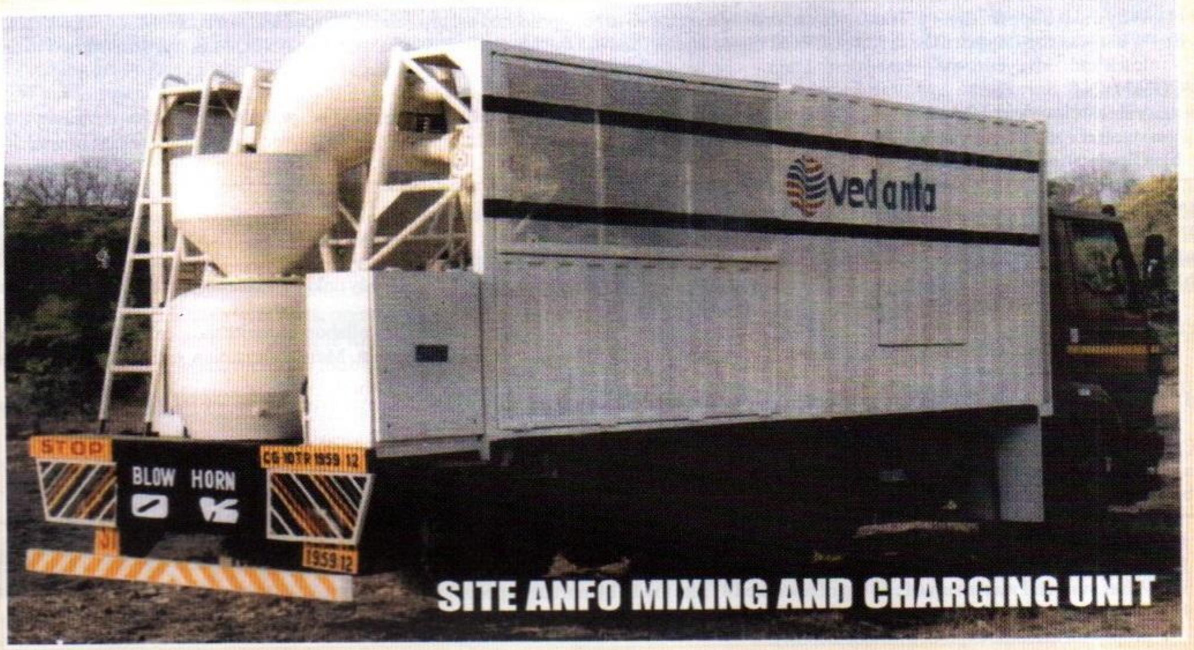
1) **INCIDENT TITLE :** 9 February 2015 **:** Detonator Explosion, MAXAM, Germany
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Electric Detonators
   b) **What happened**: An employee was handling detonators in the company laboratory. For currently unknown reasons, several of these detonators accidentally exploded.
   c) **Why did it happen theory** : The possible causes of the accident are still being investigated in collaboration with the local authorities. A team of expert investigators has been deployed and is currently actively conducting the investigation. More information will become available on completion of the incident.
   d) **What was the impact** : The employee who was handling the detonators when the accident occurred suffered severe injuries and is being treated at a specialised clinic.
3) **COMMENT**
   a) **Value of incident** : The true value of this incident can only be assessed once the investigation is complete and report issued.
   b) **Observations :** None

12

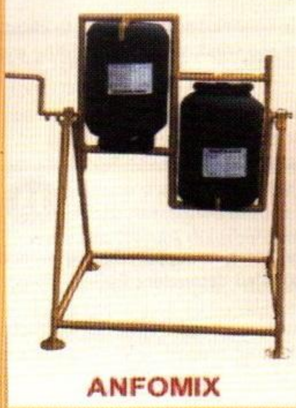
1) **INCIDENT TITLE :** 19 February 2015 **:** Propellant Paste Explosion , Turkey
2) **INCIDENT OUTLINE**
   a) **What material was involved :** 10 Kg of reworked 81 mm mod 214 mortar propellant paste .
   b) **What happened**: During the pre-rolling operation of reworked mortar propellant paste, 10 kg of propellant paste on the cylinders of the propellant machine exploded instantaneously.
   c) **Why did it happen theory** : Two theories are currently being investigated.
      Feeding of dry reworked mortar propellant paste to the cylinders of the rolling machine before the paste has been conditioned (humidity and temperature) adequately or
      Excessive heat as a result of friction on the cylinders resulting in the initiation of accumulated material in confined areas difficult to clean.
   d) **What was the impact** : There was serious damage to the rolling machine and cylinders. The roof, doors and windows of the building were damaged . There were no injuries to personnel.
3) **COMMENT**
   a) **Value of incident** : None
   b) **Observations :** None

13

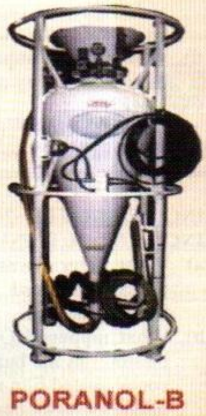
1) **INCIDENT TITLE :** 26 March 2015 : Burning Ground Explosion ,Durango,Mexico
2) **INCIDENT OUTLINE**
   a) **What material was involved :** Contaminated (emulsion) film; 2 bags with shock tubes (cut off from detonators); to support the fire: wooden pallets, cardboard, 7 decontaminated hoses from suspended watergels production, Diesel fuel; unexploded detonators from a previous burning disposal
   b) **What happened**: On a previous burning cycle, old detonators had been burned in a fire (those had actually been intended to be disposed of by blasting) in the burning ground area. Shrapnel and unexploded detonators were scattered around. Without properly cleaning the area, contaminated film with residues of sensitized emulsion and fire supporting material had been stacked for the next burning cycle. Several minutes after the burning team (2 operators) had left the burning area (by car), an explosion occurred.
   c) **Why did it happen theory** : The exact reason for the explosion is yet unknown. It is assumed that remaining detonators located within the waste material pile exploded and initiated a subsequent explosion of sensitized emulsion in the film material (estimated net explosives amount 30 50 kg). The amount of material burned (pile size) suggests that explosive material had also been under confinement.
   d) **What was the impact** : The burning platform (reinforced concrete, located in a remote area) had been severely damaged. There were no injuries.
3) **COMMENT**
   a) **Value of incident** : Regarding the disposal of old detonators, existing procedures had been violated. Detonators must not be burned in the open. The burning process of material contaminated with sensitized emulsion had not been properly risk assessed (this was a new process after a new emulsion plant had been commissioned) and existing operating procedures for burning had not been adapted to this new process. In accordance, operators had not been trained and supervised appropriately.
      The burning ground is located in a remote area and secured. Personnel had moved to a safe distance according to the existing procedure (reducing consequences).
   b) **Observations :** None



ved anta
STOP
BLOW HORN
SITE ANFO MIXING AND CHARGING UNIT



PORANOL



ABOUT THE SOCIETY

Visfotak

Explosives Safety & Technology Society

GOVERNING COUNCIL

Patron / Chairman :

Dr. E.G.Mahadevan
Formerly CMD, IDL Industries Ltd.

Patron

Prof. A.K.Ghosh
Formerly Director,
Indian School of Mines.

Members of the Executive Committee :

Ardaman Singh
President

K.H.Limsay
Hony. Secretary

Iqbal. H.Maimoon
Hon.Treasurer.

Nominated Members :

H.N.Srihari,
Formerly General Manager (R&D),
Indian Explosives Ltd.

K.D.Vakil
Director (Marketing),
Solar Industries India Ltd.

S.Menon
Sr.General Manager,
Solar Industries India Ltd.

S.R.Kate
Formerly Dy.General Manager,
IBP Co. Ltd

Nominee of the Office of the Chief Controller of Explosives, Govt. of India.

Nominee of the Office of the Director General Mines Safety, Govt. of India.

Nominee of Western Coalfields Ltd.

Secretariate Address :
Maimoon Chambers
Gandhibagh, Nagpur - 440 032

E-mail : visfotak@yahoo.com

Website : www.visfotak.org

History :

The idea of "Visfotak" as a Scientific Society took birth in 1998, on the eve of the National Seminar on Explosives Safety and Technology *Visfotak - 98,* when for the first time the three major constituents of the industry, viz, the Government Regulatory Bodies, the Manufacturers, and the Users respectively, were formally brought together on one platform to deliberate on common Concerns and Issues. Arising from the deliberations, a proposal to establish a Scientific Society exclusively dealing with the Safety & Technological aspects of the Explosives industry was unanimously endorsed.

Consequently, the Explosives Safety & Technology Society (Visfotak) was registered vide Certificate No. 410 / 99 (Nagpur) dated June 17th, 1999.

Objectives :

(a) To promote and develop modern concepts relating to safety and technology in manufacture, handling, and usage of explosives.
(b) To assist the Government of India through its appointed departments and officials in recommending, formulating policies pertaining to explosives manufacture, handling and usage.
(c) To hold seminars, workshops, conferences to promote interaction between the three constituents, viz. the Government regulatory bodies, the manufacturers of explosives and the users of Explosives, in the interest of the growth and health of the explosives industry.
(d) to collaborate with academic and research institutions in promoting the objectives mentioned above.
(e) To promote and strengthen affiliation with other world bodies / societies dealing with explosives safety and technology for exchange of information.
(f) To institute awards, fellowships and scholarships for the excellence in the field of explosives.

Governance :

The activities of the Society are overseen by a Governing Council, comprising of eminent professionals and technocrats, including nominees from the two major Regulatory Bodies ,viz, the Office of the Chief Controllers of Explosives, and the Directorate General of Mines Safety, respectively.

Institutional Association :

- **'Institute Associate Member' of Safex International . e.f 30 May, 2008**
  (Safex International is a global organization founded by the manufacturers of explosives and pyrotechnics , currently having 110 members in as many as 46 countries. For more vdetails on Safex , visit www.safex-international.org)
- **'Liaison Member ' of the Institute of Makers of Explosives (IME) , e.f. Oct 29 , 2014**
  An extract of IME's letter in this regards is shown overleaf.
  (IME is the safety and security institute of the commercial explosives industry in USA since 1923. For more details on IME , visit www.ime.org)

Membership of the Society :

The membership application form is enclosed. The application form can also be accessed and down loaded from the society's web-site .

Student Chapter:

This is an initiative launched by the society to promote the mission of the society amongst the students and academics who are , directly or indirectly associated with the science and technology of explosives. The application form for membership of the student chapter is enclosed ; it can also be accessed and downloaded from the society's web-site .

Visfotak being a Scientific Society, shall totally refrain from partisan activities of any manner or kind and shall not entertain tasks which are biased with commercial interest of its individual members.

HOMAGE

Shri Rangachari Raghavan, a founder member, passed away on 1st May, 2015 after prolonged illness.

A doyen of the 'Advertising & Mass Communication' industry in Central India, he was the singular driving force in the management of the extremely successful 'National Seminar on Explosives Safety and Technology' at Nagpur in 1998, held under the aegis of the Department of Explosives, Government of India, to commemorate the centenary of the Department of Explosives, where, as importantly, he was amongst the leading lights who inspired the idea of 'Visfotak'.

The Governing Council extends heartfelt condolences to his gracious wife and other members of his family.

Shri Rangachari Raghavan
1935-2015

IME

institute of makers of explosvies

The safety and security institute of the commercial explosives industry since 1913

October 29, 2014

Mr. Ardaman Singh
President
Explosive Safety and Technology Society - Visfotak
Gandhibagh, Nagpur - 440 032
Maharashtra, India
visfotak@yahoo.com

Dear Ardaman,

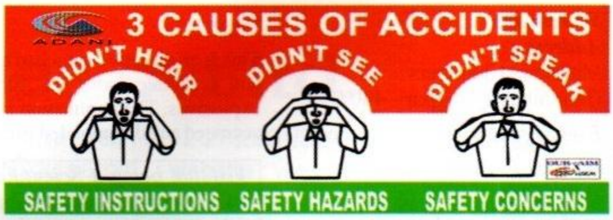
I am pleased to advise you that the IME board of governors has unanimously approved your application for liaison class membership. It is my pleasure to welcome you as our newest member.

With regard to IME standing committee assignments, you may submit to me via email your designated representatives for our standing committees, to include Technical, Transportation and Distribution (T&D), Safety and Health (S&H), Environmental Affairs, and Security. All correspondence from this office will be forwarded to you until we receive these instructions. Subcommittee assignments are self-identified, and member representatives may add or remove themselves from subcommittees at any time through our member website (www.ime.org). ....

I look forward to working with you and your association's representatives to further the interests of our industry.

Sincerely,

Debra S. Satkowiak
President



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EXPLOSIVES SAFETY & TECHNOLOGY SOCIETY

REGISTERED UNDER SOCIETIES REGISTRATION ACT MAHARASHTRA NO. 410 / 99 NAGPUR (INDIA)

MEMBERSHIP APPLICATION FORM

(Registered members will be given a Certificate and they would be entitled to participate in all the events conducted by the Society, and receive the publications of the Society free of cost).

Category of Membership : (Please tick ✓) MEMBERSHIP FEE FOR FIVE YEARS ONLY

CORPORATE MEMBER ☐
Entrance Fee Rs. 2,000/- (US $ 200)
Membership Fee Rs. 3,000/- (US $ 300)

INSTITUTIONAL MEMBER ☐
Entrance Fee Rs. 2,000/- (US $ 200)
Membership Fee Rs. 3,000/- (US $ 300)

INDIVIDUAL MEMBER ☐
Entrance Fee Rs. 1,000/- (US $ 100)
Membership Fee Rs. 1,000/- (US $ 100)

Name of Corporate Body / Institution ______

Represented by (Head - Other) * ______

* NAME IN FULL ______
(First Name) (Middle Name) (Surname)

Date of Birth ______ Designation / Current Status ______

Mailing Address ______

City ______ Pin Code ______ Country ______ E-mail ______

Telephone (Office) ______ (Home) ______ (Mobile) ______ (Fax) ______

Qualifications Educational ______ Professional ______

Year of passing ______ Institute / University ______

Nature of Industry (Explosives, Mining, Hydel Power, Cement, Highways, Irrigation, Academic / Research / Technical Services, Defence, Statutory Bodies, Other) (Please specify) ______

______

Membership of Professional Bodies, Awards, Recognitions ______

______

______

Professional Experience ______

______

Areas of Specialization ______

Mode of Payment : Payments towards Membership fee may please be made by Cheque in favour of 'Visfotak' drawn on any Bank. Add Rs. 30/- for Outstation Cheques or send a Demand Draft payable on any bank in NAGPUR.

DD / Cheque No. ______ Date ______ For Rs. / US $ ______

Drawn on ______ Bank ______

Please forward the above application along with Cheque / Demand Draft to the following address :

The Secretary General, Visfotak - Explosives Safety & Technology Society
Maimoon Chambers, Gandhibagh, Nagpur - 440 032 (India)
Tel. : 2768631 / 32 ▪ Fax : 0712 - 2768034 ▪ E-mail : visfotak@yahoo.com

Place : ______ Date : ______ Signature ______

*** Please enclose a detailed BIO-DATA and a recent passport size PHOTOGRAPH.**
For Corporate and Institutional Members enclose Bio-data of the Head or Representative

Please send your detailed address, telephones / mobile numbers, fax and e-mail ID

admas

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Visfotak **EXPLOSIVES SAFETY & TECHNOLOGY SOCIETY**

REGISTERED UNDER SOCIETIES REGISTRATION ACT MAHARASHTRA NO. 410 / 99 NAGPUR (INDIA)

MEMBERSHIP APPLICATION FORM FOR STUDENT

(Registered members will be given a Certificate and they would be entitled to participate in all the events conducted by the Society, and receive the publications of the Society free of cost).

Membership Fee : (Please tick ✓) MEMBERSHIP FEE FOR FIVE YEARS ONLY

ENTRANCE FEE ☐ Rs. 50/-

MEMBERSHIP FEE FOR FIVE YEARS ☐ Rs. 200/-

Name of Corporate Body / Institution* ____________________

Represented by (Head - Other) ____________________

*NAME IN FULL ____________________

(First Name) (Middle Name) (Surname)

Date of Birth ____________________

Name of Institution ____________________

City __________ Pin Code __________ Country __________ E-mail __________

Telephone (Office) __________ (Home) __________ (Mobile) __________ (Fax) __________

Educational Qualification ____________________

Academic Course being persued : ____________________

Membership of Professional Bodies, Awards, Recognitions ____________________

____

____

Membership of Professional Bodies, Awards, Recognitions ____________________

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Areas of Interest ____________________

Mode of Payment : Payments towards Membership fee may please be made by Cheque in favour of 'Visfotak' drawn on any Bank. Add Rs. 30/- for Outstation Cheques or send a Demand Draft payable on any bank in NAGPUR.

DD / Cheque No. __________ Date __________ For Rs. / US $ __________

Drawn on __________ Bank __________

Please forward the above application along with Cheque / Demand Draft to the following address :

Dr. N.R. Thote, Assistant Professor
(Hony. Secretary, Student Chapter
Explosives Safety & Technology Society (Visfotak)
Department of Mining Engineering
Visveswaraya National Institute of Technology, Nagpur - 440 011

Place : __________ Date : __________ Signature __________

***Please enclose a detailed BIO-DATA and a recent passport size PHOTOGRAPH.**

Please send your detailed address, telephones / mobile numbers, fax and e-mail ID

admas

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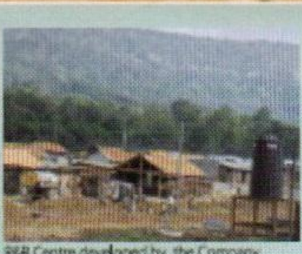
Para Military recruitment training

Medical camp at peripheral village



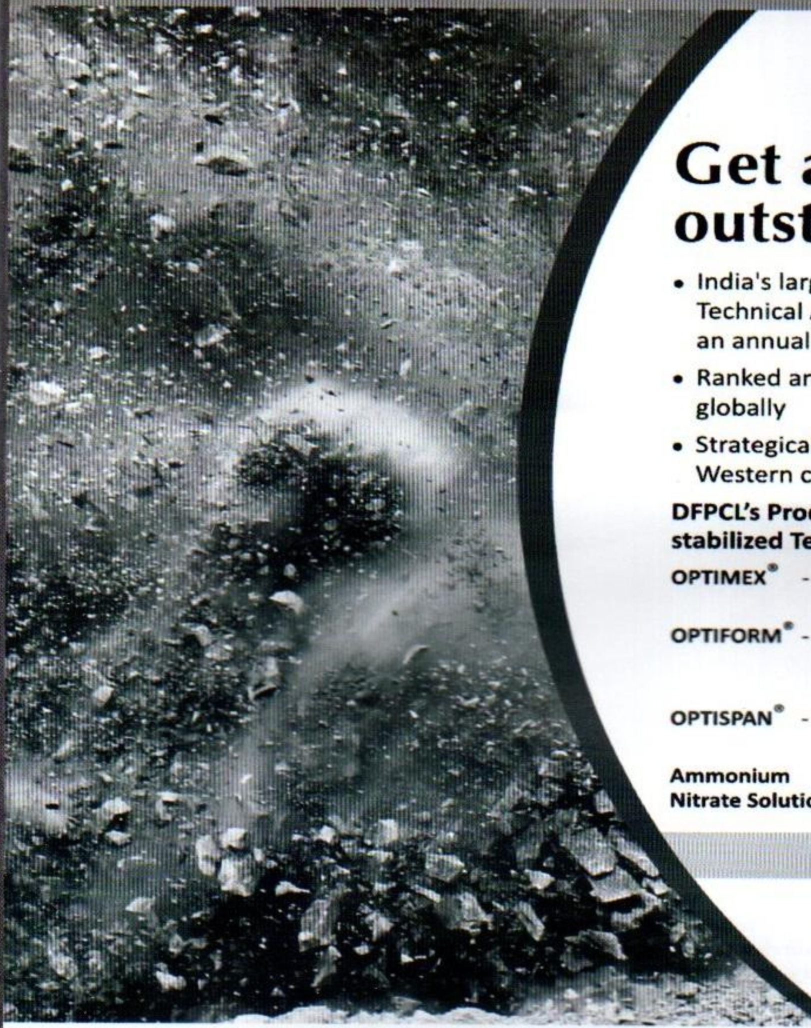
R&R Centre developed by the Company

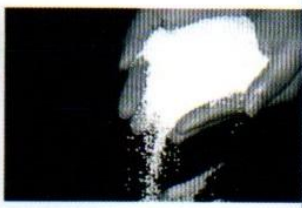
At Singereni we are committed to the growth of our nation's economy through empowerment and development programmes in the fields of education, medical, sustainable eco-management program, infrastructure and rehabilitation programmes.

- The children of the employees and local residents are trained and guided to make them prospective candidates for various vocational competitive exams
- Literacy drive for employees, women, health initiatives and health awareness.
- Drinking water, education, approach roads, street lighting and other infrastructure development in surrounding mining areas.
- Environment protection in the recent years include setting up of Automatic Dust Suppression arrangements, Sewage Treatment Plants, Effluent Treatment Plants, Bio-engineering structures on Over Burden Dumps, Clonal Plantations, Medicinal Plantations and development of Parks & Gardens.

The Singareni Collieries Company Ltd. (A Government Company)
Kothagudem Collieries - 507101, Andhra Pradesh

One Family... One Vision... One Mission - The Spirit of Singareni





Design and Produced : Cyber Space, 25/3, Ganesh Colony, Opp. Ganesh Mandir, Pratap Nagar, Nagpur - 22
Mobile : 9822921861, 9028943827 Email : ranjitcimfr@gmail.com
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