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Risk Assessment Study for Storage Explosive

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Abstract: In Malaysia, there has been rapidly increasing usage in amount of explosives due to widely expansion in quarrying and mining industries. The explosives are usually stored in the storage where the safety precaution had given high attention. As the storage of large quantity of explosive can be hazardous to workers and nearby residents in the events of accidental denotation of explosives, a risk assessment study for storage explosive (magazine) had been carried out. Risk assessment study had been conducted in Kimanis Quarry Sdn. Bhd, located in Sabah. Risk assessment study had been carried out with the identification of hazards and failure scenarios and estimation of the failure frequency of occurrence. Analysis of possible consequences of failure and the effects of blast waves due to the explosion was evaluated. The risk had been estimated in term of fatalities and eardrum rupture to the workers and public. The average individual voluntary risk for fatality to the workers at the quarry is calculated to be 5.75×10^{-6} per person per year, which is much lower than the acceptable level. Eardrum rupture risk calculated to be 3.15×10^{-6} per person per year for voluntary risk. There is no involuntary risk found for fatality but for eardrum rupture it was calculated to be 6.98×10^{-8} per person per year, as given by Asian Development Bank.

Key words: Risk assessment, explosive, fatalities, eardrum rupture

INTRODUCTION

Accidents such as at Bhopal, India in 1984 where methyl isocyanine escaped from a storage facility causing many deaths, have left the impression on the general public that storage of hazardous and toxic materials is extremely dangerous to the public. In Malaysia, the fire and explosion incident at the Bright Sparklers Sdn. Bhd. Factory at Kg. Baru Sungai Buloh on 7 May 1991 had revealed many shortcomings and the lack of understanding in handling the explosives materials.

Explosives should be handled and stored in the proper manner to avoid any adverse event occur. Explosives usually stored in the storage where safely procedures are given high attention. Fire and explosion are the two major incidents, which could occur in the storage explosives[1].

Improper handling found as the major causes in contributing the fire and explosion to occur. Due of that issue, the need for risk assessment study for storage explosive or magazine in quarry areas has become exceedingly critical due to the increasing on the number of quarry in Malaysia. Moreover the potential damage has been magnified by the proximity of many such operations have densely populated areas.

The need for risk assessment study concerning the application of hazardous and toxic materials has becomes more important in recent years. It has been found that in many cases risk assessment study of handling hazardous and toxic materials will show the storage area has the greater potential for risk to the public[2]. This is because of the much larger amount of hazardous material usually found in storage compared with process areas, although process areas have accidents more often than storage areas[3].

METHODOLOGY

Quarry and storage explosive location: Risk assessment study for storage explosive had been conducted in Kimanis Quarry Company Sdn. Bhd. It is located in Bukit Manggis, Papar, Sabah. Figure 1 shows the topography of the quarry and its surrounding area, the hill being quarried is part of Bukit Manggis, which rises to approximately 50 m and 140 m above sea level. The crusher plant is located on the southern section of the site, on a largely level ground. The magazine or storage explosive is located on the eastern side of the site, approximately 30 m from the quarry face on the north and 130 m from the main access road.

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Table 1: Hazard identification of explosive

Component	Emulate Gelatin	Detonator RDX	Cord	Safety Fuse
Physical State	Emulsion two phase Oil in water	Metals shells containing explosives with insulated metal leg wires		
Flammability	difficult to initiate	Easy to initiate		
Explosivity	Stable in nature	May detonate with impact or on heating		
Stability/reactivity	Stable in nature	Detonates with friction, impact, heat, low level electrical current and electrostatic energy		
Hazardous breakdown product	Carbon dioxide, ammonia and nitrogen dioxide	Gases produced iron, lead, carbon and nitrogen oxides		
Fire fighting	Evacuate and allow burn	Evacuate and allow burn		
Acute Health Effects				
Skin contact	Irritation and allergic reaction	Irritation and allergic reaction		
Inhalation	Not a gas	Not a gas		
Ingestion	None	None		

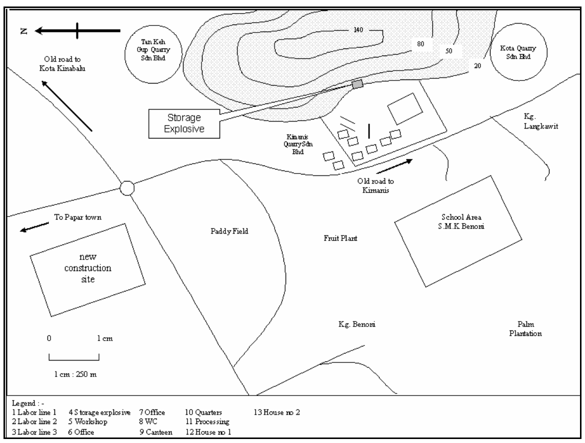

Fig. 1: Quarry and storage explosive location

Types of explosives use in the quarry: In the blasting operation as practiced by Kimanis Quarry Sdn. Bhd, an approximate amount of 1000 kg of explosive used for blasting, with an average 5 blasting per month. The bulk of the explosive energy requirement is met by using ANFO, which is obtained by mixing ammonium nitrate (AN) and fuel oil (FO). These ingredients are not explosives in nature and used to provide the bulk explosive energy when ignited as a result of a primary explosion using other readily ignitable explosives. The blasting operation is thus initiated using emulate gelatin explosives and detonated by detonating cord and delay fuses. Identification of hazard for explosives and detonator done by study on the material safety data sheets (MSDS) and others sources from literature review[3]. All the hazard data was extracted and summarized in the Table 1.

From the above one may conclude that the materials are non-toxic at normal conditions, but when involved in fire and explosion, toxic fumes of carbon monoxide, nitrogen oxides and ammonia may release. These have following exposure limits[4-6].

Table 2: Exposure limit for toxic fumes

Material	Odor (ppm)	TLV (ppm)	STEL (ppm)	IDLHV (ppm)
CO	-	50	400	1500
N_2O	-	50	150	250
NH_3	50	25	35	1000

Event tree and fault tree analysis: There are 3 basic causes that will initiate the detonation of the magazine. There are lightning strike induced detonation, static discharge induced detonation and hammer strike induced detonation

The total probabilities, taken from the above three events, suggest that it is 7.6 x 10^{-5}/yr. This is in good agreement with the value as estimated from past records. i.e. 1 x 10^{-4}/yr. This figure of 7.6 x 10^{-5} probability of accidental explosion will be used to calculate the fatality rate arising from the operation of this storage explosive.

Consequences analysis: This part of study developed a simulation programming to analyze the consequence of explosion. QBASIC programming language is used to develop the program. TNT and Probit model are the models that selected for consequences analysis. For failure scenario of accidental detonation of the explosives, consequence analyses are carried out and hazard zones are computed. The areas are which fatalities would occur can then be quantified[5].

Explosion in the storage explosive will produce blast wave, load noise, fly debris and vibration. All these will effect to the human and environment surrounding the storage explosive. The main factor which govern the magnitude peak overpressure in a blast wave from the detonation in free air are as following: (1) Distance of the wave from the center of explosion D, (2) The weight of the charge W, (3) The explosion parameters of the charge.

With the assumption, it is pessimistic to express the relationship between the weight of the explosive charge W, to the shockwaves effect at a distance D. A common empirical formula which had been widely used to estimate the blast effect of the explosive as follow:

$$D = Z\,W^{0.33} \quad (1)$$

where,
Z is the scale factor
D is the distance from the centre of explosion
W is the weight of charge in TNT equivalent kg
Where weight of charge W in TNT equivalent kg could be calculated by the following equation:

Table 3: Day time voluntarily and involuntary risk level (Probability of explosion 7.6 x 10^{-5}/yr)

Range	Fatality rate	Voluntary Receptor		Involuntary Receptor	
		Number Exposed	Fatality rate /year	Number exposed	Fatality rate/year
0-20	100%	2	7.6 x 10^{-5}	-	-
21 – 25 m	50 %	4	3.8 x 10^{-5}	-	-
25 – 30 m	1 %	14	7.6 x 10^{-7}	-	-
> 30 m	0	0	0	-	-
Total		20	1.15 x 10^{-4}	0	0

Table 4: Night –time voluntary and involuntary risk level (Probability of explosion 1 x 10^{-5})

Range	Fatality Rate	Voluntary Receptor	Involuntary Receptor	Number exposed	Fatality rate/year
		Number Exposed	Fatality rate/year		
0-20	100%	0	0	-	-
21 – 25 m	50 %	1	5.0 x 10^{-6}	-	-
25 – 35 m	1 %	0	0	-	-
> 35 m	0	0	0	-	-
Total		1	5.0 x 10^{-6}	0	0

$$W = M \times Co \qquad (2)$$

where,

M is the weight of explosive in kg

Co is conversion factor for a particular explosive

Since Z is the scale factor for the overpressure value P, the overpressure value can be estimated by using this formula:

$$P_s = \frac{1616\,[\,1 + (Z/4.5)^2)]}{(1+ (Z/0.048)^2)^{0.5} \times (1+ (Z/0.032)^2)^{0.5}\ (1+ (Z/1.35)^2)^{0.5}} \qquad (3)$$

$$P = Ps \times 101.3\ kPa \qquad (4)$$

where

P_s is the scale overpressure

P is the overpressure in kPa

Quantification of risk from all failure events: The present from the previous stage are summarized in integrated form. The results presented in a contour plot representing the overall risk arising from accidents, which could result in fatalities and eardrum rupture at the plant and its surrounding area.

The storage explosive designed to store 2000 lbs of explosives, this quantity of explosives poses a definite amount of risk explosion. The explosion overpressures depend on the peak overpressure that reaches the person. Direct exposure to high overpressure levels may be fatal. The fatality is a result of the explosion even though the overpressure that caused the structure collapse would not directly result in a fatality if the person were in a open area.

In analyzing the consequence of blast wave the probit model was chosen. Two blast wave effects to human were estimated there are; fatality and eardrum rupture. The probit equation for these two effects are as follow[5].

Effects	Probit equation	
Human fatality	$Y= -77.1 + 6.91 \ln P$	(5)
Ear drum rupture	$Y= -15.6 + 1.93 \ln P$	(6)

Where P is the overpressure value in unit N/m^2

The load noise is evaluated by use the following equation.

$$L_p = 20 \log_{10} \{\ [\ P\ ] / [\ 20 \times 10^{-6}]\ \} \qquad (7)$$

The equations (1) until equation (7) were used to develop the simulation programming by using QBASIC programming language.

Comparison of risk value: The final stage of this risk assessment will deal with a comparison between the possible risk levels arising from the option of this plant with commonly acceptable risk level.

DISCUSSION

The largest hazard zone as drive at most 111 m from the centre of explosion. On checking the layout of the quarry and its surrounding area it shows that the areas of concern are mainly in the western to the northern section where the zone covers some residential and working areas where the workers are affected.

For persons exposed to the hazards, 46 workers located within the plant site are assumed to be within the hazard zone 111 m. In particular, all 20 workers are assumed to be within the hazards zone of 30 m. Only 2 workers is assumed to be within the 100% fatality probability of 20 m during the loading and unloading of explosives. It is also assumed that 4 other operators, including the driver, are located outside the bund within 25 m of the storage explosive. A fatality probability of 50 % is assumed. It is also reported 3 persons will stay overnight at the plant site. This will constitute the number of workers voluntarily exposed to the risk at night.

For persons exposed to the risk involuntarily, it is noted that the 113 m hazards zone extends to cover 2 houses to the western of the quarry. However, for quantification of fatality risk the persons in these house

Table 5: Day time voluntarily and involuntary risk level for ear drum rupture (Probability of explosion 7.6 x 10^{-5}/yr)

Range	Fatality rate	Voluntary Receptor		Involuntary Receptor	
		Number Exposed	Probability rate /year	Number exposed	Probability rate /year
0 – 20 m	100 %	4	7.6 x 10^{-5}	-	-
20 – 46 m	50 %	14	3.8 x 10^{-5}	-	-
46 – 55 m	30 %	10	2.28 x 10^{-5}	-	-
55 – 72 m	10 %	6	7.6 x 10^{-6}	-	-
72 – 111 m	1%	4	7.6 x 10^{-7}	11	7.6 x 10^{-7}
Total		46	1.45 x 10^{-4}	11	7.6 x 10^{-7}

Table 6: Night –time voluntary and involuntary risk level for ear drum rupture (Probability of explosion 1 x 10^{-5})

Range	Fatality Rate	Voluntary Receptor		Involuntary Receptor	
		Number Exposed	Probability rate /year	Number exposed	Probability rate /year
0 – 20 m	100 %	1	1.0 x 10^{-5}	-	-
20 – 46 m	50 %	0	0	-	-
46 – 55 m	11 %	0	0	-	-
55 – 72 m	3 %	0	0	-	-
72 – 111 m	1%	2	1.0 x 10^{-7}	11	1.0 x 10^{-7}
Total		3	1.01 x 10^{-5}	11	1.0 x 10^{-7}

is not included and it is only used for quantification risk of eardrum rupture.

Computational of fatality: Event though there are 3 cases to the explosion scenario, the final effect will eventually be the same. The previous section describes the population distribution of the hazard scenario, it is now possible to compute the total fatalities due to the accidental detonation of the explosives stored in the magazine.

For day time computation, it is assumed that the exposed populations are all present in Table 3 tabulates the breakdown of affected population with respect to the hazard zones, and the total involuntary and voluntary risk level. With 20 workers present within the hazard zone 30m, a total fatality rate of 1.15 x 10^{-4} / yr is calculated. With workers is thus calculated to be 5.75 x 10^{-6} /yr /person, which is much lower then the acceptable level 1 x 10^{-4}/yr /person[7].

There is no involuntary fatality risk were found in this study because the hazard zone for fatality not exceed the residential area. For night time it is assumed that only 3 workers stay at the site to do security. However due to the fact that the causes of accidental detonation of explosive has been reduced to only that caused by lightning strike, the probability has dropped down from the daytime value of 7.6 x 10^{-5} /yr to 1 x 10^{-5} /yr. The single worker is assumed to stay at the front entrance of magazine (25 m within the wide sand big bund) and 2 persons stay in front entrance of quarry, where the distance is exceed 30 m.

Computational for eardrum rupture: For day time computation, it is assumed that the exposed populations are all present. Table 5 tabulates the breakdown of affected population with respect to the hazard zones, and the total involuntary and voluntary risk level. With 46 workers present in the quarry, a total ear drum rupture rate of 1.45 x 10^{-4} / yr is calculated, and voluntary risk is thus calculated to be 3.15 x 10^{-6} /yr /person.

The total number of individual involuntary level is calculated to be even less. With 11 persons affected and a total ear drum rupture rate of 7.6 x 10^{-7} the individual involuntary risk level is calculated to be 6.9 x 10^{-8} /yr/person.

For night time it is assumed that only 3 workers stay at the site to do security. However due to the fact that the causes of accidental detonation of explosive has been reduced to only that caused by lightning strike, the probability has dropped down from the daytime value of 7.6 x 10^{-5}/yr to 1 x 10^{-5} / yr. The single worker is assumed to stay at the front entrance of magazine (25 m within the wide sand big bund) and 2 persons stay in front entrance of quarry, 350 m from the magazine. The night time individual voluntary risk level is calculated to be 3.36 x 10^{-6} /yr/person.

CONCLUSION

It is always an element of risk associated with the use, storage and the handling of explosives. Risk from the magazines could be reducing if good design practices are incorporated into its building. In this risk assessment, the probability of explosion of magazine has been quantified. The explosion scenario of the magazine has also been modeled and its hazards range has been determined. The degree of risk of the above hazard is best compared to commonly accepted risk level.

Asian Development Bank[7] in its ERA guidelines suggested that for a project to be acceptable, its potential cumulative risk must not exceed the commonly accepted individual voluntary risk, which is 10^{-4} fatalities per person per year for workers.

In addition, if the risk of the operation extends to its neighboring population, such a risk shall not exceed the commonly acceptable risk level of 10^{-6} fatalities per person per year for surrounding residents.

The average individual voluntary risk for fatality to the workers at the quarry is calculated to be 5.75 x 10^{-6} per person per year, which is much lower than the acceptable level. Eardrum rupture calculated to be 3.15 x 10^{-6} per person per year. There is no involuntary risk found for fatality but it is found for eardrum rupture and calculated to be 6.9 x 10^{-8} per person per year. Based on the above assessment, it is conclude that due to the operation in magazine, contents are the consequential impact to the surrounding population is within environmental guideline values.

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