A Study into the Relationship between Crater Parameters and Quantities of Explosives in the Scenes of IED Explosions

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ABSTRACT: An explosion, whether accidental or intentional, typically results in serious damage to property and harm to people. The investigation of explosion has a long history in forensic science and covers incidents ranging from accidents in home or workplace to major terrorist attack. One of the most important tasks requiring the set of skills that only the forensic scientists possess is the preliminary identification and quantification of the explosive substance used in an incident. This determination can provide important information early on for the investigator and may play a major role in the direction the investigation will take. Evidence of an explosion may take the form of a crater or other damage which may provide some information facilitating and estimating the mass of explosive material used. The size of the crater is an important evident for the blast occurrence and the size vary depending upon the quantity and the type of explosive used. In this paper, a numerical study on craters formed by explosive loads on soil surface is presented. This pilot study, the first of kind in Malaysia to study the relationship between the crater parameter and quantity of explosive used. Considering the realistic crime scenarios, seven test charges (IED) loaded with different type and quantity of energetic materials representing high and low explosive packed in different types of confinement were used in the blasting exercise and presented the findings. The study was conducted at Tapah, Perak in collaboration with Royal Malaysian Police Force.

Keywords: Forensic Science, IED explosions, crater mark, explosive mass

Introduction

An explosion, whether accidental or intentional, typically results in serious damage to property and harm to people. Rather than the well rounded investigative expertise of a Sherlock Holmes, explosion investigations require personnel highly experienced in post blast investigation representing a variety of highly specialized disciplines [1]. Bombs are a nightmare to peace loving people and security agencies. A bomb is designated to explode in the way the bomber wants to explode it. Today, when we call it a criminal bomb or Improvised Explosive Device (IED) or Home Made Bomb (HMB) or Unexploded Ordinance (UXO) which means explosive devices planted or delivered with the intention of causing injury, death and damage to property. Improvised Explosive Devices, or shortly IEDs, are often used by terrorists in committing bombing crimes, lifting behind quite subtle evidences that puzzle the crime scene investigators on their work to unravel the mystery of the bombing crime. The IED could be in any size and shape [2]. The military explosives are normally known as MED or Military Explosive Device which confirm to standard specification and hence are easily identifiable. In contrast, IEDs are bombs manufactured illegally by miscreants and these do not conform to any specifications. Device construction is based on material availability and the creator's knowledge and imagination and hence these IEDs post a great challenge to the law enforcing agencies [3]. Pipe bombs are a common preferred improvised explosive device since construction is straightforward, and both metal and plastic pipes are readily available. Many of the pipe fillers are propellants which may include black powder, smokeless powder, and fireworks powder, and even match heads which can be purchased without special permit. Over the years, law enforcement has developed robust protocols for processing bomb scenes and analytical procedures for identifying and quantifying explosives.

Various situations exist in detection and identification of explosives in forensic cases. These may include improvised explosive devices, explosive residues at crime scenes, suspect shipments, and screening of hidden explosives carried by travelers on airlines [4, 5]. The role of forensic experts pertain to identification and quantification of the explosive substance used, reconstructing the explosive device and comparing component of the explosive device with the related materials recovered from the possession or premises of the suspects thereby providing scientific evidence before the court of law. In case of terrorist attacks or other intentional actions using explosives, it is extremely important the information that can be obtained from the crater generated by the blast waves. When the charge exploded in the soil, along with the explosion energy release, the soil near explosives was crushed, squeezed, part of soil near the ground surface was ejected, finally the crater was formed [6]. The crater formed by the blast can be used as a diagnostic tool. For example, the focus of the explosion and the mass of the explosive used in the attack can be deduced by examining the location, geometry and dimensions of the crater [7] as shown in Figure 1.

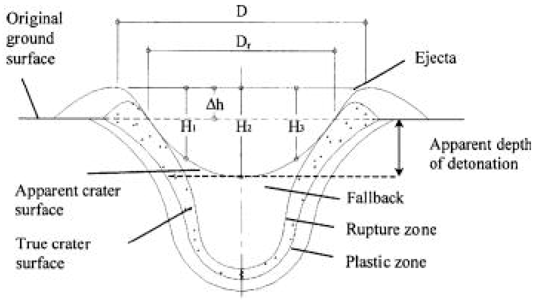

Figure 1: Definitions of the crater dimensions [7] (Note: D- apparent crater diameter; D_r- crater diameter)

This article deals with the study on the relationship between the crater parameters and quantity of explosives by blasting IEDs, assembled with different known mass of high and low power explosives with varying confinements (cloth, PVC and steel pipe) and presented the findings.

Materials and Method

Place of blasting exercise

As suggested by PDRM, the blasting exercise was conducted at “Chendriang driving range” situated in between Chendriang and Tapah (Figures 2 & 3), Perak state.

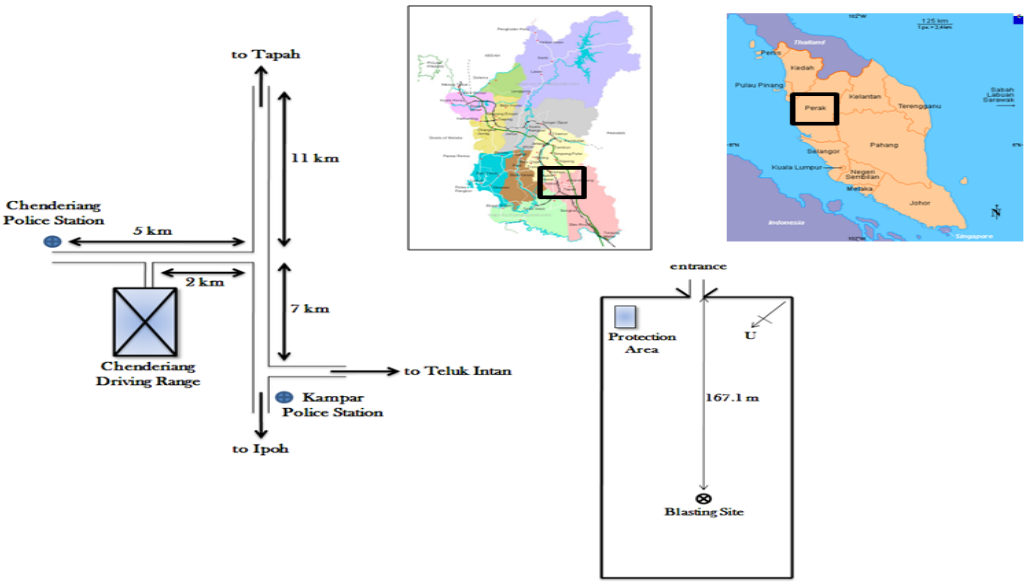

Figure 2: Rough sketch showing the place of blasting exercise

Figure 3: Place of blasting exercise at "Chenderiang driving range"

The improvised explosive devices under study were assembled by Ipoh Bomb Disposal Unit, PDRM with different mass of high and low power explosives in different containers as designed by the author (TN) and are shown in Figure 4.

(1)

(2)

(3)

(4)

(5)

(6)

(7)

Figure 4: Assembled bombs (IEDs) with varying confinement and quantity of explosive

The blasting exercises were conducted by Post Blast Investigation (PBI) team, Forensic Lab, PDRM, Cheras and Ipoh Bomb Disposal Unit (*Unit Pemusnah Bom*), Perak and under the supervision of the main author (TN) and Supt. Soo Me Tong (Figure 5).

Figure 5: Officers involved in the blasting exercise

Considering the realistic crime scenarios, seven test charges (IED) loaded with different type and quantity of energetic materials representing two major classes of explosives viz. the high explosive (HE) and low explosive (LE) packed in different types of confinement (cloth, PVC and steel pipe) were used in the blasting exercise as shown in Table 1 and Figure 4.

The Post-Blast Investigators (PBI) of the Royal Malaysian Police technique is based on the 10-person concept as in Bureau of Alcohol, Tobacco and Firearms (ATF). The equipment and tools used include PBI kit, detonating tools, excavation equipment, searching gear, documentation equipment sample collection equipment and other required tools by PBI unit as being used in real bombing scenes at Malaysia.

Table 1: Explosive types, mass and confinements

No.	Explosive type	Confinement	Mass of explosive chemicals used (g)
1	Low Explosive	Cloth	200.0
2	Low Explosive	PVC pipe	150.0
3	High Explosive	PVC pipe	150.0
4	High Explosive	Clothes	200.0
5	High Explosive	PVC pipe	300.0
6	Low Explosive	PVC pipe	300.0
7	High Explosive	steel pipe	300.0

The officers involved in the blasting exercises were given briefing to ensure scene safety, and evidence collection procedure. Except the main author (TN), all bomb sample information were anonymized and the exercise was performed blind.

The blasting exercises were conducted by the trained PDRM bomb experts. After each blast the post blast debris were collected and measured the crater dimension and recorded. Each charge was electrically detonated and the craters resulting from explosions (Figure 6) were examined (Figure 7) in determining the approximate quantity of explosive charge used.

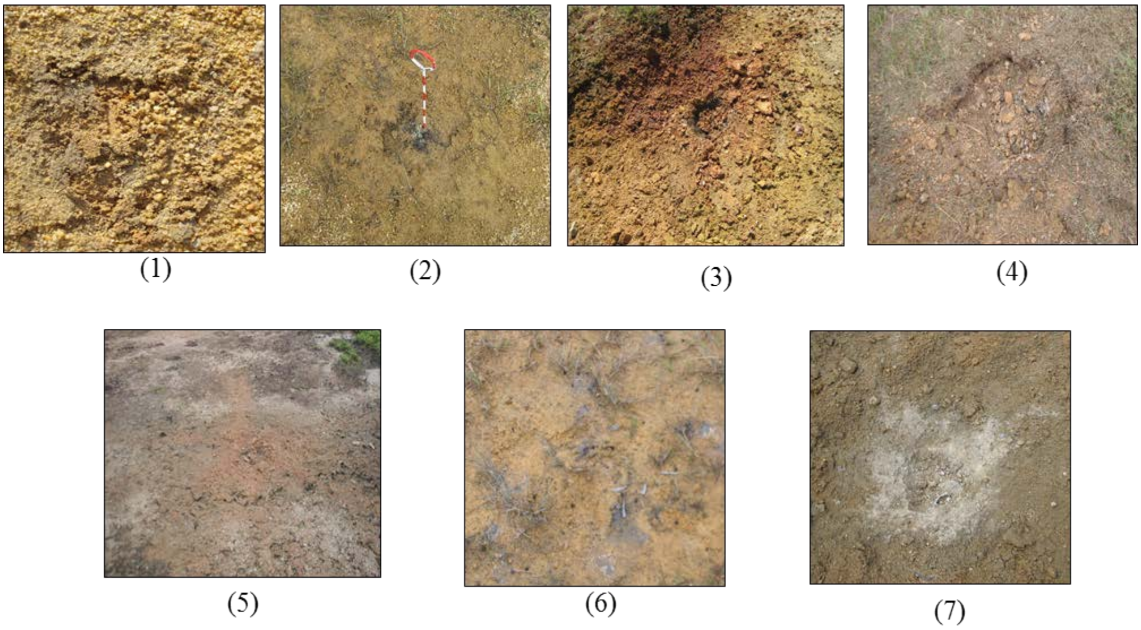

Figure 6: Crater formation in different types of IED explosions

Figure 7: Crater measurement after the blast

Results and discussion

The seat of explosion in a bomb scene can be confirmed by the presence of crater at the blast site. The craters are the depressions caused by explosions on the ground. After each blast, the crater dimensions were measured and recorded. Some empirical equations proposed for the evaluation of crater dimensions were ascertained from the literature. Two different formulae were used to estimate one for low explosive and another for high explosive. Nevertheless, they were obtained for particular type of soils, shapes of explosives, ranges of explosive mass and depth of explosive and they present considerable variability.

The formula used to estimate the quantity of high explosive from the crater parameter is as shown below [2].

$$V= KW1.14$$

where, V is the crater volume (cubic feet), W is the mass of high explosive used (lbs) and K is a constant. The value of K is 0.4.

The following formula was used to estimate the quantity of low explosive from the crater parameter [7-9].

$$D = 0.8W^{1/3}$$

where, D is the diameter of the crater (m) and W is the mass of low explosive (kg).

The formula used to estimate the crater volume is as shown below [10].

$$V = (1/12)abh\pi$$

where, V is the crater volume (m^3), a is the diameter from the major axis (m), b is the diameter from the minor axis (m) and h is crater depth (m).

The crater measurements, the estimated and actual mass of low and high explosives used are presented in Table 2 and quantification of low and high explosives based on the formulae are as shown below.

Quantitative estimation of low explosive from crater parameter

Formula; $D = 0.8W^{1/3}$

Where,

D = diameter of the crater, m

W = weight of explosive, kg

Model calculation (Explosion No.6)

$D = 0.8W^{1/3}$

$0.497 = 0.8W^{1/3}$

W = 0.23977 kg

=**239.8g**

Quantitative estimation of high explosive from crater parameter

Formula; $V= KW1.14$

Where,

V = volume of crater, cubic feet

W = weight of explosive, pounds (lbs)

K = constant, 0.4

Model calculation (Explosion No.5)

$V = KW1.14$

0.35935 = (0.4) (1.14) W

W = 0.77620 lbs

= **352.1 g**

Table 3 shows the estimated and actual mass used in the blasting exercise and the percentage of deviation.

Table 2: Type, mass of explosives, confinement and crater measurements

No.	Explosive type	Confinement	Mass of explosive chemicals used (g)	Major axis, a, cm	Minor axis, b, cm	Depth, h, cm
1	Low	Cloth	200.0	40.5	36.0	0.7
2	Low	PVC pipe	150.0	34.4	29.5	1.2
3	High	PVC pipe	150.0	41.0	37.5	7.2
4	High	Cloth	200.0	53.5	46	10.0
5	High	PVC pipe	300.0	54.0	52.0	13.0
6	Low	PVC pipe	300.0	49.7	41.5	1.5
7	High	Metal pipe	300.0	55.0	54.0	14.0

Table 3: Comparison between the estimated and actual explosive mass of explosive substance used

No.	Explosive type	Confinement	Actual mass (g)	Estimated mass (g)	Deviation, (+/-)	Percentage of deviation, %
1	Low	Cloth	200.0	129. 8	-70.2	35
2	Low	PVC pipe	150.0	79.5	-70.5	47
3	High	PVC pipe	150.0	106.7	-43.3	28
4	High	Cloth	200.0	237.4	+37.4	18
5	High	PVC pipe	300.0	352.1	+52.1	17
6	Low	PVC pipe	300.0	239.8	-60.2	20
7	High	Metal pipe	300.0	401.1	+101.8	33

The crater formation is a complex mechanism. If the cratering problem is generalized, it can be said that the size and shape of an explosively generated crater are dependent upon: the quantity and type of explosive used, the type of soil and its water and mineral content, the shape of the explosive charge in which the cratering takes place, and the method of emplacement of the charge and its position relative to the medium-air interface. Even very carefully performed cratering tests give deviations in the dimensions measured of the order of 10%, while differences of as much as 30% to 40% are common [11]. For example, explosion of PETN1 and PETN2, both were of 10-ton TNT-equivalent high explosive (HE) charges at virtually the same location; yet, one crater was considerable shallower and wider than the other. In spite of these, it is possible to estimate the approximate mass of explosive used from the crater parameter, enough to precede the investigation further.

Another concern of this study is the fragments and its velocity. Recovered pipe bomb fragments, exploded under controlled condition provided wealth of forensic information regarding the power and quantity of explosive used, as well as characteristics of initial device used [12]. The formula used in this calculation was adopted from the International Forensic Seminar Proc, 2007, National Research Institute of Police Science, Explosion Section in Chiba, Japan and is:

$$V_o = \sqrt{2E}\left[\sqrt{\frac{W_c/W_m}{1+0.5(W_c/W_m)}}\right]$$

where, Vo is the metal velocity of fragments (km/s), √2E is the Gurney constant (km/s), wm is the mass of the container (g) and the Wc is the mass of charge (g). The Gurney constant is specific to particular explosive types.

Model calculations (Explosion No. 1)

$$V_o = \sqrt{2E}\left[\sqrt{\frac{W_c/W_m}{1+0.5(W_c/W_m)}}\right]$$
$$= 1.51\left[\sqrt{(200.0/60.0)/(1+0.5(200.0/60.0))}\right]$$
$$= 1.51\left[\sqrt{3.33333/2.66667}\right]$$
$$= 1.6882 \text{ km/s}$$
$$= \mathbf{5,538.81 \text{ ft/s}}$$

Explosion No. 2

$$V_o = \sqrt{2E}\left[\sqrt{\frac{W_c/W_m}{1+0.5(W_c/W_m)}}\right]$$
$$= 1.51\left[\sqrt{(150.0/150.0)/(1+0.5(150.0/150.0))}\right]$$
$$= 1.51\left[\sqrt{1/1.5}\right]$$
$$= 1.2329 \text{ km/s}$$
$$= \mathbf{4,044.95 \text{ ft/s}}$$

Explosion No.7

$$V_o = \sqrt{2E}\left[\sqrt{\frac{W_c/W_m}{1+0.5(W_c/W_m)}}\right]$$
$$= 2.93\left[\sqrt{(300.0/1690.0)/(1+0.5(300.0/1690.0))}\right]$$
$$= 2.93\left[\sqrt{0.17751/1.08875}\right]$$
$$= 1.1830 \text{ km/s}$$
$$= \mathbf{3,881.23 \text{ ft/s}}$$

Figure 8 shows the different types of assembled bombs and the fragments collected after the blast. The steel pipe has fragmented into large number of small sizes fragments. The fragments produced by the PVC pipe were smaller number of large size fragments. Table 4 shows the fragment velocity of different types of improvised explosive devices.

Figure 8: Different types of IED bombs and bomb fragments collected after the blast

Table 4: Fragment velocity of different types of improvised explosive devices

No.	Explosive type	Container	Container mass, Wm(g)	Mass of charge, Wc/(g)	Gurney constant, (km/s)	Fragment velocity, ft/s
1	Low	Clothes	60.0	200.0	1.51	5, 538.81
2	Low	PVC pipe	150.0	150.0	1.51	4,044.95
3	High	PVC pipe	150.0	150.0	2.93	7,841.21
4	High	Clothes	60.0	200.0	2.93	12, 007.87
5	High	PVC pipe	150.0	300.0	2.93	9,612.86
6	Low	PVC pipe	150.0	300.0	1.51	4954.07
7	High	Metal pipe	1690.0	300.0	2.93	3,881.23

(Note: Wm= weight of container (g); Wc= weight of charge (g))

Based on the instrumentation technique, the post blast residues were collected in the blasting site for analysis and the identified explosive types were recorded and published [13]. In case of terrorist attacks or other intentional actions using explosives, it is extremely important the information that can be obtained from the crater generated by the blast waves. The role of forensic scientists in examining explosives and their debris both in the crime scene and forensic science laboratory is largely concerned with those explosives that are illegally used. Extensive research activities in the field of blast loads have taken place in the last few decades. Most research is related to underground explosions and there are many experimental results related to underground explosions. In case of underground explosions, the size or crater depends on the weight of explosive and buried depth of the charge [14]. Only a few papers are concerned with explosions at ground level. The present investigation deals with the estimation of explosive mass from crater parameter by blasting improvised explosive device with various types, loads and confinements.

The result of the investigation revealed that high explosively generated crater diameter is longer compared to low explosively generated crater even when similar masses of explosives were used. In cloth confinement, high and low explosive filler with similar mass (200g) were blasted. The result indicated that high explosively generated crater diameter was found longer (major 53.5 cm & minor 46 cm) than low explosively generated crater diameter (major 40.5 cm & minor 36 cm). Correspondingly high explosively generated crater depth was found to be deeper (10 cm) than low explosively generated crater depth (0.7cm). In PVC pipe confinement, similar mass (300g) of high and low explosive were detonated. Here again, high explosively generated crater diameter was found to be longer (major 54.0 cm & minor 52.0 cm) than low explosively generated crater diameter (major 49.7 cm minor 41.5 cm). Also high explosively generated crater depth was found to be deeper (13 cm) compared to low explosively generated crater (1.5 cm). The detonation of PVC and metal pipe with similar mass of high explosive filler generated craters with almost similar size craters although the metal pipe generated little bit higher size than PVC. The detonation of metal pipe with 300g HE filler generated larger crater (major axis - 55.0 cm, minor axis -54.0 cm, depth – 14 cm) than PVC pipe (major axis - 54.0 cm, minor axis -52.0 cm, depth – 13 cm) with 300g HE filler.

Another observation made in the investigation is that if two PVC pipe bombs charged with different mass of similar explosive type were detonated, the size of the explosively generated crater is directly proportional to the quantity of explosive used. According to Hopkinson's law, if charges of the same explosive, differing in weight but not in shape, are detonated, the explosive effects are proportional to the linear dimensions of the two charges. Thus, a sphere of TNT that has a diameter twice that a second sphere will, upon detonation, produce twice as big as a crater and twice as much damage. Within the range of charge weights (150g and 300g) involved, the data both from actual bombing and from the experimental work confirmed satisfactorily to Hopkinson's law.

Another interesting feature observed in the detonation of high explosive filled PVC pipe (5th blast) is the formation of soil ejecta with flash like pattern (Figure 9). This may be due to gas flow pattern during blasting [15]. Similar type of oil flash pattern was observed by Nataraja Moorthy when conducted IED blasting exercise using ANFO with varying compositions of AN and FO (Figure 10) at Tenaga Kimia Sdn. Bhd. campus, Batu Arang, Selangor, Malaysia [16]. This oil flash pattern could be observed only when the FO proportion exceeded the actual ANFO specification in IED explosion.

Figure 9: Soil flash pattern in HE filled PVC blast

Figure 10: Oil flash pattern in ANFO filled blast [16]

Fragmentation is an important effect produced when expanding gasses of an explosion cause any container in which the explosive is encased to expand and fragmented. These fragments are propelled to the air at high velocity. Besides that, debris also included as fragmentation in case of uncased explosive. The reason is the uncased explosive which located inside a steel baggage or room is encased by its surrounding. Then, parts of the enclosure will be propelled outward and away from the point of initiation. Thus, debris will propel outward at high velocity as dirt and stone in explosions which take place on or below the surface of the earth. In this investigation, the fragment velocity of cloth in cloth confinement is highest compared to PVC and in turn iron pipe. The fragment velocity caused by high explosive filler IED is comparatively higher than low explosive filler IED.

The high explosive filler IED produced large number of small size fragment pieces whereas the low explosive filler IED produced smaller number of bigger size fragment pieces (Fig 8). It is a valuable indication to recognize the power of explosive even when chemical residue is not recovered [12].

Conclusion

A numerical study of craters produced by different explosive loads with different confinements was presented in this paper. Taking into account the results obtained, the following conclusions and observations may be drawn:

- The crater formulae may be used in a real crime scene to estimate the approximate mass of explosive material used.
- Appropriate formula may be used to estimate the mass of low power explosive and high power explosive.
- Explosively generated crater volume is directly proportional to the quantity of explosive material used.
- High explosively generated crater size is larger than low explosively generated crater when similar mass of explosive was used.
- High explosively generated crater depth was found to be deeper compared to low explosively generated crater when similar mass of explosive was used.
- Explosively generated crater volume is dependent on the type of container when mass explosive filler remain constant *i.e.* PVC pipe produced smaller size crater than steel pipe of similar weight of explosive.
- The fragment velocity is inversely proportional to the type of container i.e fragment velocity is in the decreasing order from cloth to PVC and to iron pipe.

The limitation of the study was the use of relatively small mass size (150g-300g) of explosives which needs to be considered in drawing conclusions and in respect of future studies investigators prediction. The shape of the explosive charge also has some influence on crater size for explosions on the ground surface. Hence similar research may be performed in Malaysia by using large mass and different shape of explosive charges in different soil surfaces (gravel, sand, concrete etc.) including other parameters so as to come up with new findings in forensic perspective.

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