International Academic Institute
for Science and Technology

International Academic Journal of Innovative Research
Vol. 1, No. 1, 2014, pp. 6-20.

ISSN 2454-390X

International
Academic
Journal
of
Innovative Research

www.iaiest.com

Analysis of the explosion phenomenon and the blast wave equations for gaps using smoothed particle hydrodynamics

Hossein Foruzesh [a]

[a]*Master of Civil Engineering Structures, Islamic Azad University of Bushehr, Iran*

Abstract

This study aims to analyze the phenomenon of the explosion and the blast wave equation for gaps. Today with the advances in science and technology, new needs and demands have happened in the field of structure engineering. Many researches has been done so far about the behavior of structures and explosion, but given that the study of subject of explosion on structures has a particular importance, in this study the blast waves caused by explosives is first investigated and then charges and its parameters will be evaluated and Finally, in order to achieve a more simple approach and strategy to deal with facing questions and problems in the following, the effects of the blast wave structure and characteristics will be studied. At the end, the proposals in order to reduce the impact of adverse consequences resulting from blasting operation are presented in general.

Keywords: Explosion phenomenon, blast wave, gap.

1-INTRODUCTION

The Nuclear Test Ban Treaty which was adopted in 1960 Prohibits and stops any nuclear testing in the atmosphere. However, the comprehensive effects of blast waves on a large scale on the structures still remain a debatable and researched matter for Global Studies. Biennial series of nuclear explosion simulations in America provide to allow continuing this type of research. The latest research can be named the project of Direct Course (1983), as an aerial explosion of 600 tons of ammonium nitrate and oil fuel (ANFO) which is embedded in spherical chamber on top of a tower with a height of 50 m and also surface half spherical explosions using the maximum 4,500 tons (ANFO), such as projects Minr Scale (1985), Misty Picture (1987), Misers Gold (1989) and Distant Image (1991). The documents of this experiments is well collected in symposium reports MAPS.

The use of blast tunnels to assess structural responses in a nuclear blast environment is the characteristics of works that is now accomplished in United Kingdom, France, Germany and Canada.

The blast tunnel using explosion of relatively small amounts of conventional explosives has been created by the institute of Nuclear Weapons in Fluence of England. The maximum pressure about 45 kPa and duration of the positive phase over 300 ms, in the diameter range of 10.7 meters, is obtainable. Similar facilities are also available at Center d′ Etudes de Gramant close to Toulouse, France.

The experiment is created by using compressed gasses which are first in 7 pressured cylinders. Explosion cutting of gas-tight diaphragms result in the release of compressed air to produce an explosion simulation. The newest facilities that are working for the same purpose can be named the facilities located in Reiteralpe in Germany, which use the ranged and compressed air tunnels to simulate a nuclear explosion. In this regard, given that the aim of this study was to investigate the introduction of explosion phenomenon in different situations and conditions, this paper has been provided for understanding this phenomenon.

2-Explosion definition

Explosion releases huge amounts of energy which also warming up the surrounding environment creates many local pressures. The pressure variations moves around and out and also by creating the impact, appears as blast wave. When an explosive with high-intensity blasting is compressed and exploded, almost 100% of its released energy is converted into energy.

In the following sections, the blast waves caused by the explosion of explosive materials in the open air and on the ground are described and existing conditions in explosion wave front are studied.

3- Blast waves caused by explosives materials

When an explosive start to react, following steps one after another occur: first, the explosion reaction produces hot gases that can have pressures of 300-100 kb and temperature of 3000-4000 ° C. then this explosion gasses is highly expanded and extended, so that surrounded air is saturated from them and as a result a layer of compressed air that is the blast wave, is formed in front of these gases. This layer contains the greatest amount of energy released by the explosion. When the gasses from the explosion are expanded, at the same time with the wave front moving outward and away from the source, the compressed air pressure in the blast wave front is reduced by increasing the distance. Finally, as explosion gases gradually become cooler and more expanded, their pressure is reduced up slightly less than the atmospheric pressure. This is because that although the static pressure of the gases may be close to the atmosphere, but as long as the gas molecules have mass and move, the propagation continues until losing of momentum. The gasses emissions have been too much at this stage or in other words, have found to be "over expansion" and the result is that we will see a backflow to the source. This flow shows the low pressure difference between atmospheric conditions and gasses pressure. The blast wave form affects the low pressure area where the pressure is less than atmospheric pressure and is called the negative phase. With the return of gases and air that have been away from the source by pressure, the conditions return to equilibrium state. The equation of motion that is necessary for the description of a blast wave is a complex equation that has been first written numerically by Brode and then has been modified empirically by Kingery. We analyze the outlines of the contents in the following.

4- Blast wave equations for cylindrical gaps

In order to achieve a more simple approach and strategy to deal with facing questions and problems in the following, we study the effects of the structure and characteristics of the blast wave from the three position. The first situation is inside the explosives, where detonation of explosives begins. The second region is the area outside the explosive namely its surrounding region that the blast was formed. Finally, in the end sections, the interaction of blast wave with a hard object will be discussed in which blast wave produces the structural load.

5- Inner environment of gaps

Consider a cylindrical gap containing of explosive with radius R_c that is shown in Figure 1.1. Initial of reaction is done from the center of the charge and blast wave front has a radius R_d. Reaction zone is also a narrow area behind the wave front. By referring to Figure 1-1 in Area A (where the reaction is complete), the parameters of pressure, p, density, ρ, particle velocity, U, and temperature, T, all vary according to the radius of the charge center, r, and time, t. The detailed relationship between pressure, radius and time depends on the type of explosive that compresses the outside. The area of B which is located on top of an un reacted thin zone at ambient pressure,P_{ex}, and temperature, , has a stasis particle acceleration equivalent to zero. Its energy, , is per unit mass (specific energy) and the speed of sound in the un reacted explosive material is C . The area of C is in the conditions of environment atmosphere and thus its pressure is atmospheric pressure, P_0, its temperature, T_0, and particle acceleration is equivalent to zero. The air also has a special energy, e_0, and the speed of sound, C_0.

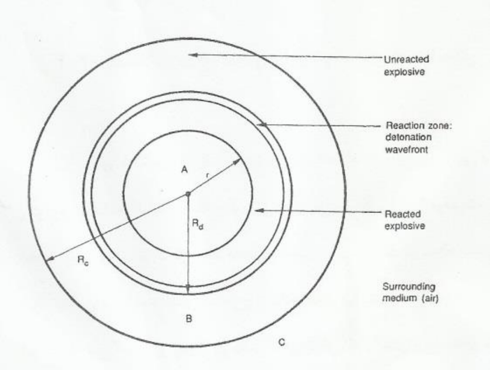


Fig. 1.1 inner environment of gaps

In order to achieve equations that can evaluate and analyze pressure fluctuations and particle acceleration and other items, consider element control volume with radius r inside the material reacted and or exploded, as shown in Figure 1.2.

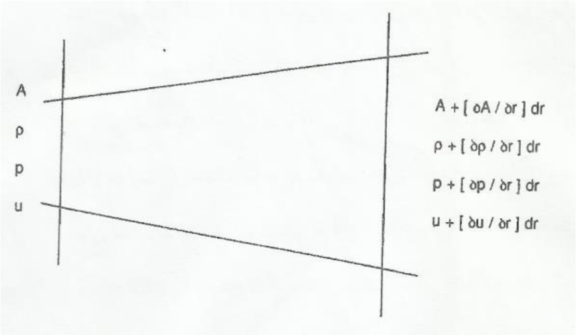


Fig. 1.2 control volume

For control volume, the principle of the conservation of mass means that the mass entered minus the mass exited should be equal to the residual mass caused by density change. Thus, it can be written as:

— — — —

Where A is cross-section num1of control volume.

Simplified form of the equation is:

— — — —

— — — —

— — — ——

The principle of the conservation of momentum means that the sum of all forces acting on the material in control volume should be equal to multiply mass times acceleration.

— — —— —

That, in the equation, the first term is related to the force exerted on the front 1, second term is the force on the front 2 and the third term is the force on the surface between front 1 and 2 which have been separated in radial directions, (Figure 1.2). Equation 1-5 can be simplified as follows:

— — —

— —

The equation can be also written as:

— —

Whenu —, then we will have:

— — —

Now by substituting it in equation 1-8, the following equation is derived:

— — –—

According to the energy conservation principle, for a mass unit of material, an increase ind is equal to one de plus work done times change the volume of material, pdv, which is the increase in internal energy of the specific volume, v. Thus, the first law of thermodynamics is written as follows:

Since that the specific volume is equal to –, therefore — — and:

—

Equation 1-8 will be:

—

And dividing the equation by T, we will have:

— — ——

Where is the change in the entropy of the system. Dividing the equation by and arranging we will have:

Here, there is also the need for an equation of state that can be written as:

Where R is the gas constant.

Consequently, we have the following equation for the internal energy of the system.

Where C_v is the Specific heat at constant volume. Here, there are 5 equations and 6 unknowns (pressure, density, particle velocity, temperature, internal energy and entropy). So if we want to solve these problems, the sixth equation will be needed that with the creation of several assumptions for the sixth equation, the general form can be written as follows:

Here, it can be used the same relation (CJ) Chapman - Jouguet that in connection with explosion process to provide a particular pattern.

Here, D is the velocity of detonation wave (about 7000 m/s in TNT), is the particle velocity in behind of wave front of explosion and is the speed of sound in explosion gasses.

Boundary conditions for solving the above six equations are:

$\rho($

Therefore, there will be the possibility of use of numerical solutions in order to achieve results for the 6 parameters.

6- Outer environment of gaps

As observed, the system of above equations was in connection with the explosion processes. Here, it can be evaluated blast wave parameters in a similar way. This situation is illustrated in Figure 1.3.

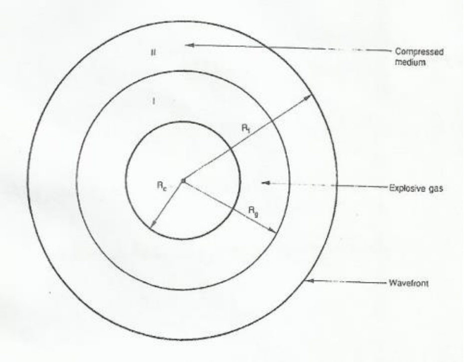


Fig. 1.3 Outside environment of gaps

7- Outside of gaps

As seen in the Fig 1.3, in the section I namely, the area of expanding explosive gases, the motion can be expressed through the analysis of equations 1-1 to 1-20. In section II, that is the area of surrounding compressed air, the motion can be achieved as with previous. As previously mentioned, the boundary conditions can be also precisely defined:

The particle velocity at r = 0 is often zero. The particle velocity at the intersection between the explosion gasses and the blast wave sequence in ($r = R_g$) is equal to the equivalent particle velocity with expansion rate of the intersection. The pressure in the two adjacent environments is the same while the density in the two environments is not the same. The pressure in the explosion wave front with the radius R_f is equal to and particle velocity is u_s.

Therefore, we will have:

$$(R\quad t)\qquad (R\quad t)$$

$$(R\quad t)\qquad (R\quad t)\quad \frac{\quad}{\quad}$$

$$(R\quad t)\qquad (R\quad t)$$

Where, suffix g refers to explosive gases, suffix m represents the surrounding environment and the suffix s is denoted to the wave front of the explosion. So we once again have found 6 equations for 6 unknowns we have that are solvable numerically.

8- The parameters of the wave front of the explosion

The parameters of the blast front that were proposed first time by Hugoniot, Rankine in 1870, describe the normal shocks in ideal gasses. The parameters which have a special importance, is found in different references such as Liepmann and Roshko [42]. The equations to calculate the speed of the blast wave front u_s, the air density ρ_s behind the wave front, and dynamic pressure q_s include:

$$\sqrt{\frac{\qquad}{\qquad}}$$

Where p_s is the peak of maximum static pressure $p_0$of the surrounding air of front of the blast wave, $\rho_0$is a density of above air, and C_0 is the speed of sound in air at the atmospheric pressure. The changes of dynamic and static pressure in wave front in free air can be obtained by using equation 21-1 and considering $101p_0$. The results are seen in table 1.1.

Table 1.1 Dynamic and static pressure changes [42]

200	110
350	290
500	518
650	778

By observing the table, it can be concluded that up to the peak of maximum static pressure about KPa, the amount of dynamic pressure numerically is less than p_s. In the higher maximum pressure than $p_s = 500$KPa, the dynamic pressure outshines the static pressure. In figures 1.4 and 1.5, equations 25-1 and 26-1 are depicted. Brode's analysis [42], results in the following outcomes about the amount of the peak of maximum static pressure in the near field ($p_s > 10bar$) and the environment of the far field ($0.1 < p_s < 10bar$).

$0/1$

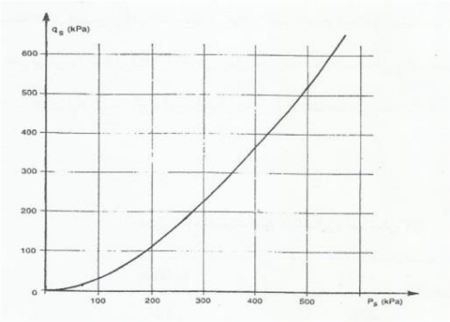


Fig 1.4 dynamic pressure versus the maximum lateral pressure

Z is the scaled distance, which can be obtained from the following equation:

——
–

Where R is the distance from the center of charge in m, and W is the mass of the charge in kg of TNT. The use of TNT as a reference explosive in relation to Z is a relatively accepted contract. The first step is to quantify the blast waves caused by materials except the TNT, a real mass conversion of charge to equivalent mass of TNT. The easiest way to achieve this purpose, is the use of conversion factor for some explosive materials which are presented in Table 1-2 (The table is derived from the work of Mr. Baker) [41] Thus, a charge of 100 kg of RDX, is equivalent to 118.5 kg of TNT, since the ratio of two special energies is 118.5. One of the alternative solutions is the use of two conversion factor that the choice of each one depends on the fact whether or not the peak of the maximum pressure matches with the main explosive and TNT equivalent? Table 1-3 that is derived from the documentations 1-855-TM5 provides the examples of the alternative conversion coefficients.

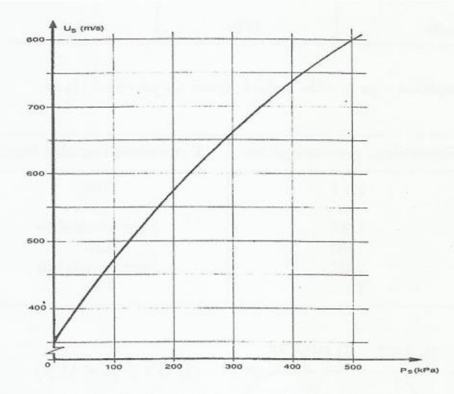


Fig 1.5 the speed of wave front versus the maximum lateral pressure

In the meantime, there are other numerical and laboratory solutions to calculate the parameters of the wave front. The equations which are presented below are proposed by Henrych and similar with Brode equations.

Table 1.2 energy conversion factor of explosive materials relative to TNT.

Explosive	**Mass Specific energy kJ/kg**	**TNT Equivalent /Q**

Amatol 80/20 (80% ammonium nitrate 20% TNT)	2650	0.586
Compound B (60% RDX, 40% TNT)	5190	1.148
RDX (Cyclonite)	5360	1.185
HMX	5680	1.256
Lead azide	1540	0.340
Mercury fulminate	1790	0.395
Nitroglycerin (liquid)	6700	1.481
PETN	5800	1.282
Pentolite 50/50 (50% PETN 50% TNT)	5110	1.129
Tetryl	4520	1.000
TNT	4520	1.000
Torpex (42% RDX, 40% TNT, 18% Aluminium)	7540	1.667
Blasting Glatin (91% nitroglycerin, 7.9% nitrocellulose, 0.9% antacid, 0.2 water)	4520	1.000
60% Nitroglycerin dynamite	2710	0.600

Table 1.3 pressure and impulse conversion factor of explosive materials relative to TNT

Explosive	Equivalent pressure factor	Equivalent impulse factor
Composition B (60% RDX, 40% TNT)	1.11	0.98
PETN	1.27	Not available
Pentolite	1.40	1.07
Tetryl	1.07	Not available
TNT	1.00	1.00

Measurements and predictions accuracy about the near-field is less than the average to far field. This is perhaps due to the complexity of current processes. These processes involve the formation of the blast wave near the charge, where it is difficult to quantify the explosive gasses. The diagram of figure 1.6 displays the maximum pressure p_s versus scaled distance. The problem is that a wide range of non-compliance results are related to the values of Z that are less than 5.

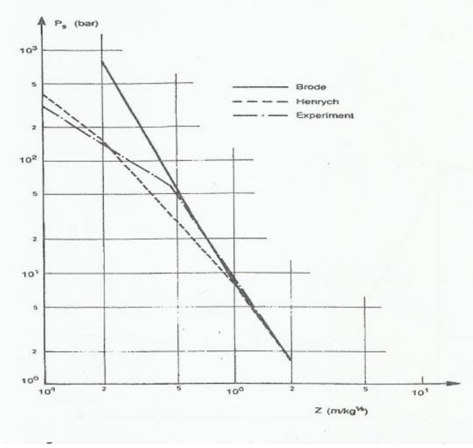


Fig 1.6 the peak of the maximum lateral pressure in contrast to scaled distance: a comparison between experimental and analytical results

9- Other important parameters of blast wave

Other important parameters of the blast include: T_s the period of time of the positive phase in which the pressure is more than ambient pressure, I_s Special momentum of wave that is the area under the curve of time - pressure of wave arrival time (t_a) to the end of the positive phase and is calculated through the following formula:

You see a pressure - time diagram of sample related to the blast wave in the open air in Figure 1.7. Here is the greatest amount of suction (pressure lower than ambient) in the negative phase

that continues for . In fact, this amount is the low density component of the blast wave. The following solution is provided by Brode to achieve :

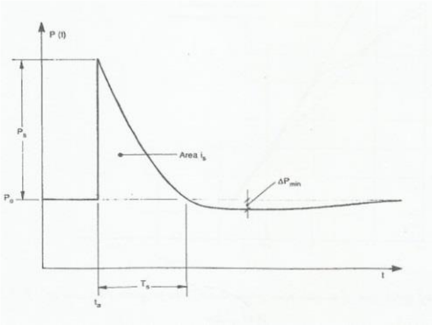


Fig 1.7 Time-pressure diagram of explosion wave

The time duration of negative phase (suction) can be obtained from the following equation:

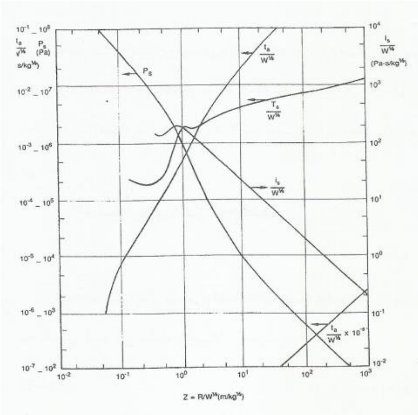
–

And the special momentum related to the suction phase would be:

$$\approx \mathrm{i}\left(1 - —\right)$$

And at the end λ_{rw}, is the dilution wavelength (low density) that is based on speed of sound 340m/s in air, and in terms of meter the following can be obtained:

In the meantime, one of widely used method for introducing the significant parameters of the blast wave is to plot the diagram that illustrates the parameters versus scaled distance. Figure 1.8 is derived of some references such as the Baker and Baker et al and design code of TM5-1300. The suction changes versus the measured distance are illustrated in figure 1.9. These parameters can also be illustrated graphically versus the distance of one kilogram gap of TNT. The graph is taken from Kingery and Bulmash.



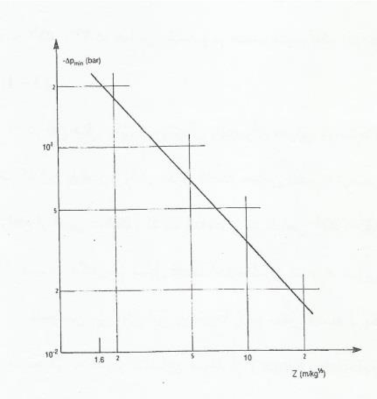


Fig 1.9 the suction versus the scaled distance Fig 1.8 the parameters of blast wave for spherical gaps of TNT

The dynamic pressure q_s, the speed of the blast wave front u_s, and waveform parameter b that will be used in equation 34-1to explain the history of the pressure-time of blast wave, should be added to the list of the important parameters of blast wave. Table 1-4 shows the parameters in contrast to Z (scaled distance).

9-1 pressure diagrams of blast wave

Pressure-time history of a blast wave is often described by an exponential function such as Friedlander equation. This equation can be presented as follows.

$$\left(1 \quad -\right)\exp\left(- -\right)$$

In this equation, b is the waveform parameter and function of the peak of the maximum pressure p_s, and as noted in Table 1.4 contains values that are taken from available scaled distance diagrams in reference 41. These approximations are satisfactory for many purposes. Therefore, when a cautiously approach is desired for pressure-time history it can be often used of descending linear branch in designing (line I, figure 1.10). In another way, if we want that the amount of momentum is equal the main mode in ideal waveform, we use the line II in Figure 1.10, and in this case, the actual and approximate descending area under the curve, are equal.

Table 1.4 parameter values of waveform

Z (m/kg1/3)	B
0.4	8.50
0.6	8.60
0.8	10.00
1.0	9.00
1.5	3.50
2.0	1.90
5.0	0.65
10.0	0.20
20.0	0.12
50.0	0.24
100.0	0.50

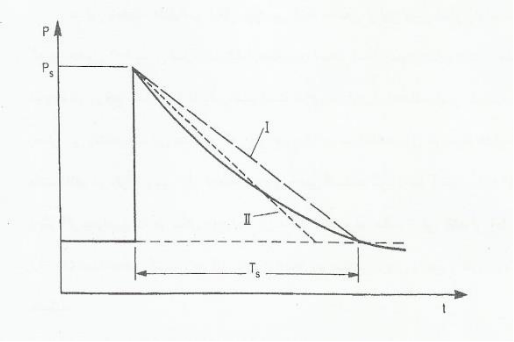


Fig 1.10 blast wave curves: Equality of Impact, conservative, actual

10-Conclusion

By performing a comprehensive search about conducted researches and with the aim of achieving the available experiences in relation to the theoretical principles and fields of application of the standard method, the studies were conducted with the following topics.

1. Because the stabilizer methods induce damping into the system, the choice of smoothing amplitude of the velocity field will have a significant impact on results.

2. Due to the uniform expansion of the particles in the blast wave propagation modeling in the vacuum, the use of stabilizer method of artificial viscosity is not required.

3. Perform the theoretical study to determine the effect of particle arrangement in the stability.

4. Review the effect of weight functions types in answers accuracy.

5. Generalization of the algorithms provided in the gas phase for three-dimensional environments.

6. Carrying out the theoretical study to increase the efficiency of written programs, especially for enhancing the capability for modeling the heavy problems with more number of particles.

11- References

[1] G.R. Liu, Meshfree Methods: Moving beyond the Finite Element Method,CRC Press, 2003.

[2] G.R LIU, M.B. Liu, Smoothed Particles hydrodynamics a meshfree particle method, World Scientific Publishing, 2003.

[3] TMS-1300, Design of structures to resist the effects of accidental explosions. US Dept. of the Army Technical Manual (1987).

[4] TMS-855–1, Fundamentals of protective design for conventional weapons. US Dept. of the Army Technical Manual (1987).

[5] T. Zhu, S.N. Atluri, A modified collocation method and a penalty formulation for enforcing the essential boundary condition in the element free Galerkin method, Computational Mech. Berlin 2(1998)2 1–222.

[6] T.Liszka, Orkisz, The finite difference method at arbitrary irregular grids and its application in applied mechanics, Comput. Struct.11(1980)83-90.

[7] R.A. Gingold, J.J. Monaghan, Smoothed Particles Hydrodynamics: theory and application to non-spherical star. R. Astron. Soc. Monthly notices, 181 (1977)375389.

[8] L.B Lucy, A numerical approach to the testing of the fission hypothesis, Astronomical Journal.82 (1977) 1013-1020.

[9] Li Shaofan, W.K. Liu, Meshfree and Particle methods and their applications, Appl. Mech. Rev. 55, no 1 (2002).

[10] P.D. Smith, J.G. Hetheringtan, Blast and Ballistic loading of structures.

[11] H. Ostad, S. Mohammadi, Solid and Gas Interaction Using Meshfree Particle Methods, A thesis of Graduatee, (2008).