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Investigation of explosive loading and its type of operation

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Abstract

The subject of evaluating the vulnerability and strengthening of structures against various natural and artificial factors such as earthquake, wind, fire and explosion, etc., has been the focus of most civil engineering researchers in recent years. However, the engineering profession is generally not well aware of the design of static or dynamic structures to resist the explosion. In this research, it has been done by presenting materials about the introduction of explosion and the components of this type of loading, and by examining the parameters in explosive loading and the relationship between them, Review and presentation of comprehensive information in this regard has been discussed.
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Keywords:blast load, blast wave, scale, retrofitting, modeling

1. Introduction

The explosion can threaten human life, it can also cause damage to residential and industrial buildings and cause the loss of security, communication, transportation system, and services. Since Iran is located on the earthquake belt, seismic behavior is often considered in the design of buildings. However, the engineering profession in general is not well aware of the design of static or dynamic structures for blast resistance, because in the past the blast load was rarely considered an important factor in building design, and the dynamic effects of the blast structure were only research subjects in a limited number of laboratories. It was working. The cost of creating a safe environment for explosion research is high, and for this reason, certain organizations such as military agencies, government research facilities, and large industrial explosives factories work in this field. More than a few decades have passed since the introduction of computational tools based on the finite element method in the analysis and design of structures, but there is still a lack of a suitable tool in this field that can accurately analyze the structure against explosive loads. Also, in the new design methods, more detailed analyses will be needed to better estimate the capacity of the structure against the loads on it.

2. Definition of explosion

An explosion is a sudden, rapid, large-scale release of energy. According to the nature of this type of phenomenon, explosions are classified into three types: physical, nuclear, and chemical. In physical explosions, energy may be released from the

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catastrophic failure of a gas seal or even the fusion of two liquids at different temperatures. In a nuclear explosion, energy is released from the formation of different atomic nuclei by the redistribution of protons and neutrons within the range where the nuclei interact, while the rapid oxidation of fuel elements (carbon and hydrogen atoms) is the main source of energy in chemical explosions.

3. **Blast loading**

As a result of the explosions, a wave is released from the air, which is known as a shock wave. It is a dense air wave that moves outward from the source of the explosion in a spherical form at a very high speed. In the explosion, there are two important independent parameters, which are the number of explosives that is equivalent to TNT (W) and the distance of the explosives from the structure (R). These two quantities' results are introduced as the Z parameter (scale distance). The use of Z allows us to have a concise and effective expression of the blast wave for a wide range of situations. For example, the Oklahoma bomb in 1995 weighed 1814 kg and R distance of 4.5 meters [3].

$$Z = \frac{R}{W^{\frac{1}{3}}} \quad (1)$$

in which W is the amount of explosives and R is the distance of explosives from the structure.

The observed characteristics of blast waves are influenced by the physical parameters of the blast source. Figure 1 shows the explosion pressure profile. At input time t_A, the pressure position suddenly increases to the overpressure value P_{s0}. Then this pressure decreases to ambient pressure at time t_d, continues to negative pressure (which produces a partial vacuum), and finally returns to ambient pressure at time t_d. The quantity P_{s0} is usually considered the peak pressure.

In the pressure-time diagram, two main stages can be observed: the upper part of the time axis is called the positive stage (up to time t_d), while the part below the time axis is called the negative stage. The negative phase lasts longer and is less intense than the positive phase. When the distance from the explosion source increases, the duration of the positive phase also increases, as a result, the amplitude in this phase decreases. If the amount of explosives is close to the structure, we will have a larger explosion with more intensity on concentrated parts of the structure, while if the explosives are placed at a distance from the structure, we will have a less intense explosion with a uniform distribution over the entire structure.

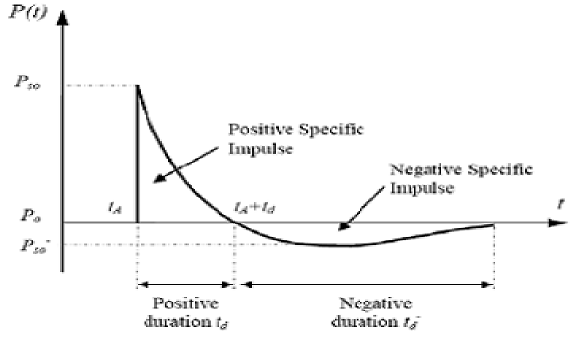

Figure 1 - pressure-time diagram of the blast wave

4. Explosives

The constituent materials of this phenomenon (explosion) can be divided into two primary or secondary types based on their sensitivity to ignition. The primitive type of these materials can be easily detonated by a simple ignition caused by a spark, flame, or impact. Materials such as mercury folinate and lead Azide are examples of this category. When the second type of material bursts (explodes), it produces explosive waves (shocks) that can cause a lot of damage to its surroundings. TNT and ANFO are examples of this type of material [5].

An explosion occurs when a large amount of energy is generally exerted on the explosive. The general characteristics of the explosive substance are determined by using parameters such as the amount of energy, energy density, energy release rate, and the power of the explosive substance. When the explosive material is ideal, regardless of the energy density and power of its source, the explosion can be described using one parameter, the total energy [1].

Before the parameters for an explosion can be derived, the equivalent mass of TNT is required. There are several ways to express the TNT equivalent, but the simplest is the ratio of the mass-specific energy of the actual explosive to the mass-specific energy of TNT. The mass-specific energy of TNT is equal to 6700 kJ/kg. The table below shows the specifications of some explosives and conversion coefficients to TNT equivalents. According to what was said, in most cases of explosives used for military or industrial purposes, TNT is the reference explosive and the power of the explosive is usually determined by the weight of TNT. In cases where the explosive material is other than TNT, the strength of the explosive material is obtained by using the TNT equivalence factor.

5. Scale rules

The characteristics of the blast wave depend on both the energy released from the explosive and the blast environment. These properties can be measured under controlled conditions in experiments and used as a basis for obtaining information about other explosions using the explosion scaling law. In explosive loading, scaling the characteristics of the blast wave is a common method and several methods have been proposed to estimate the characteristics of the blast wave. By using scaling laws based on laboratory results, it is possible to estimate the characteristics of the explosion wave resulting from the desired value and distance; But assuming full gas and regardless of gravity and viscosity, these laws are not suitable for some strong shock waves or distances close to the explosion source. In the following, two of the most used of these rules are reviewed.

The most common method for scaling the explosion is the Hopkins-Kranz method or the third root, which is shown in Figure 2 [2]. This method was first related by Hopkins in 1915 and later independently by Kranz in 1926 based on the similarity of the wave characteristics of explosions that are at the same scaled distance, when two different explosive charges are made in similar atmospheric conditions.

This law states that two explosive charges of different sizes from the same explosive will produce the same overpressure (P_S) time; which have the same scaled distance (Z) and of course have the same location and atmospheric pressure [5] that is:

$$\frac{R_1}{W_1^{\frac{1}{3}}} = \frac{R_2}{W_2^{\frac{1}{3}}} \quad (2)$$

That is, the explosive charge W_2 in the distance R_2 will create an overpressure equal to the overpressure of the explosive charge W1 in the distance R1 when the above relationship applies.

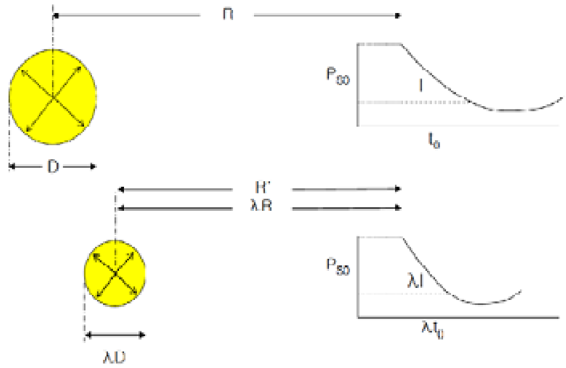

Figure 2- Hopkins-Kranz scale rules

Another one of these laws is the Sachs scaling law. Sachs proposed his relationship in 1944. Based on that, the dimensionless overpressure value according to equation 3 and the dimensionless momentum according to equation 4 can be considered as unique functions of the scaled distance. These equalities are used in equation 5 [2].

$$\overline{P} = \frac{P}{P_0} \quad (3)$$

$$\overline{I} = \frac{ia_0}{E^{1/3}P^{2/3}} \quad (4)$$

$$\overline{R} = \frac{RP_0^{1/3}}{E^{1/3}} \quad (5)$$

In recent relations, a_0 and P_0 are the speed of sound in the atmosphere and the base pressure, respectively.

The studies of Doi and Esparza showed that the Hopkins-Kranz scale is a special case of the Sachs scale [1] In fact, the Sachs scale is the same method as the Hopkins-Kranz scale in the same atmospheric conditions between the laboratory data and the existing conditions.

6. Blast wave reflection

When the blast wave hits a very large rigid surface with a zero-degree impact angle, the direction of airflow in the blast wave is gradually reversed and the static pressure on the surface increases to the reflected pressure, which is called face-on loading. When the reflection process is complete, the reflected wave propagates in the opposite direction from which it came. The maximum reflected pressure Pr can be obtained using Rankine's relation for an ideal gas [4]:

$$P_r = 2P_s\left[\frac{7P_0+4P_s}{7P_0+P_s}\right] \quad (6)$$

If the C_r coefficient is defined as the ratio of P_r to P_s, we can determine the maximum and minimum values of C_r. When P_s is only slightly greater than atmospheric pressure, the lower limit of C_r will be 2. When P_s is much higher than atmospheric pressure, the upper limit for C_r can reach up to 20.

7. Parameters of the blast wave front

The parameters of the blast wave front are of particular importance. The overpressure profile is usually characterized by parameters such as blast wave arrival time (t_a), explosion base overpressure (P_{s0}) and blast wave transit time (t_0) as shown in Figure 3. These parameters, which are a function of the strength of the explosive material, the distance of the explosion point to the measurement location, and the impact angle, are obtained analytically or experimentally.

The analytical solution of these parameters was first expressed by Hugonit and Rankin to describe shocks in an ideal gas. These equations for the speed of the blast wave front Us and the maximum dynamic pressure q_s are expressed as follows [4].

$$U_s = \sqrt{\frac{6P_s+6P_0}{7P_0}}.a_0 \quad (7)$$

$$q_s = \frac{5P_0^2}{2(P_s+7P_0)} \quad (8)$$

where P_s is atmospheric pressure and a_0 is the speed of sound in air at atmospheric pressure. Broad has provided the following equations to obtain the static overpressure in a spherical explosion [4].

$$P_s = \frac{6.7}{Z^3} + 1bar \quad (P_s > 10bar) \quad (9)$$

$$P_s = \frac{0.975}{Z} + \frac{1.455}{Z^2} + \frac{5.95}{Z^3} - 0.019bar$$
$$(0.1 < P_s < 10bar) \quad (10)$$

Other parameters of the mass explosion wave are the explosive charge (W) and the actual distance from the center of the explosive to the desired point (R) and the scaled distance (Z), which were explained in the previous sections. Other parameters of the blast wave are: the duration of the positive phase Ts, the positive impact, which is the surface under the pressure-time diagram from the time ta to the end of the positive phase:

$$i_s = \int_{t_q}^{t_a+T_s} P_s(t)dt \quad (11)$$

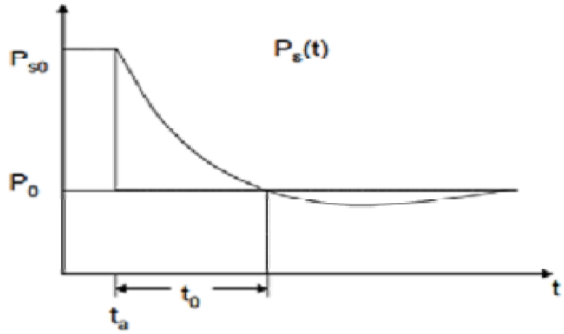

Figure 3- The overall pressure profile due to the wave propagation resulting from the explosion

An example of a pressure-time diagram is shown in Figure 4.

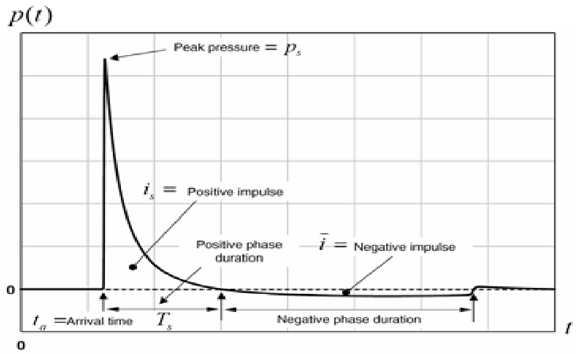

Figure 4 - Pressure history due to a free blast wave in the air

Several methods have been proposed to calculate the explosion parameters. Brad divided the explosion base pressure into two areas Close $P_{s0} > 10\,\frac{kgf}{cm^2}$ and far $0.1 < P_{s0} < 10\,\frac{kgf}{cm^2}$. He presented the following relationships to calculate the base pressure of the explosion [4].

$$P_{s0} = \frac{6.7}{Z^3} + 1 \quad (P_{s0} > 10kg/cm^2) \quad (12)$$

$$P_{s0} = \frac{0.975}{Z} + \frac{1.455}{Z^2} + \frac{5.85}{Z^3} - 0.019$$
$$(0.1 < P_{s0} < 10kg/cm^2) \quad (13)$$

Brad's relations are in good agreement with the experimental results in the middle and far fields, while

Henry's relations are in good agreement with the experimental results in the near field.

$$P_{s0} = \frac{14.072}{Z} + \frac{5.54}{Z^2} + \frac{0.357}{Z^3} + \frac{0.00625}{Z^4} \quad (0.05 < Z < 0.3) \qquad (14)$$

$$P_{s0} = \frac{6.194}{Z} + \frac{0.326}{Z^2} + \frac{2.132}{Z^3} \quad (0.3 < Z < 1.0) \qquad (15)$$

$$P_{s0} = \frac{6.662}{Z} + \frac{4.05}{Z^2} + \frac{3.288}{Z^3} \quad (1.0 < Z < 10.0) \qquad (16)$$

8. Overpressure profile

When the explosion parameters in the air such as the maximum overpressure Ps0, the duration of the positive phase of the explosion t0, and the arrival time of the wavefront ta, as discussed, the profile of the explosion wave can be determined using approximate models such as Flynn's linear model, Etheridge's exponential model and the relation Friedlander calculated [1]. The different states of the blast wave to the surface include three states of surfaces parallel to the movement of the wavefront, surfaces behind the blast wave front, and surfaces opposite to the blast wave front.

9. Simulation and computer programs

In recent years, numerical simulation has become a very important tool in the investigation of an explosion in complex geometries. Many researchers around the world have published results that show the effectiveness of this method. Air3d code has been used to calculate the explosion on urban buildings [6]. Calculation methods in the field of reducing explosion effects are generally divided into two types; Estimation of explosive loads and calculation of structural response to loads.

Computational programs for estimating blast and structural response use both analytical and semi-empirical methods. The programs that use the analytical method are divided into two types coupled analysis and non-coupled analysis. In coupled analysis, blast simulation is related to structural response. In this type of analysis, Computational Fluid Mechanics (CFD) models are used to estimate blast loads simultaneously with Computational Solid Mechanics (CSM) models for a structural response. Considering the movement of the structure during the calculation of explosive loads, the pressures caused by the movement and damage can be predicted more accurately. Examples of this type of computer code are ABAQUS, LS-DYNA, DYNA3D, and AUTODYN.

The estimation of the load resulting from the explosion in the air can be done through various software. ConWep, AT-Blast, and BlastX can be mentioned in this software. AT-Blast is a tool that can determine the amount of explosive charges in open space. This software allows the user to specify the maximum and minimum range of the explosion, the weight of the explosive material, and the impact angle. This software can calculate the speed, time, pressure, momentum, and duration of the positive phase by getting the information. ConWep software can calculate the effects of conventional weapons of war using the equations and curves in TM5-855-1. This software only can estimate the load resulting from the explosion in the open environment.

10. Summary and conclusion

In this article, the type of explosive loading and parameters related to this type of loading has been investigated. As mentioned, the effects of the explosion in complex environments such as the reflection of multiple blast waves, the negative phase of the wave, etc. can be easily modeled in the codes. CFD modeling. Simplified analytical techniques and semi-empirical methods often ignore these effects. Therefore, the modeling of building groups in dense urban centers can only be done with advanced CFD codes.

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