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WAVE MECHANICS OF BLAST AND ITS EFFECT ON STRUCTURE

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Abstract —*Explosion has become a common phenomenon for human beings. Use of controlled explosion for advancement of human race can be easily observed in our surrounding. Whereas terrorist organizations are using the destructive properties of blast to cause loss of lives and damage to structures. Explosion are categorized on basis of their nature as physical, nuclear and chemical. Explosion creates an overpressure which causes damage to surrounding. This paper summarizes some of the important phenomenon's associated with blast wave mechanics. Also the paper gives brief idea of how an explosion affects a RCC structure*

Keywords- *Explosion, Blast loading, TNT, Shock wave, Scaled wave, Over pressure*

1. INTRODUCTION

Explosion has been a part of human life since its origin. Word 'Explosion' is derived from Greek word "Exploderic" which means driving out people by making loud banging. Explosion creates a Blast wave which travels through a series of compression and rarefaction. Recently the destructive properties of a blast have been used for causing damage to life and properties. Use of vehicle bombs to attack particular targets has become a feature of all terrorist organization around the world. A strong blast wave in vicinity of a building causes catastrophic damage resulting in loss of lives and collapse of structure. Explosion are categorized on basis of their nature as physical, nuclear and chemical. Physical explosion includes volcanic eruption, bursting of compressed gas cylinder or meteoroids impact. Nuclear explosion consist of chain reaction between protons and neutrons of an radioactive element where as instantaneous oxidation of carbon or hydrogen molecules is main source of chemical explosion. Internal Combustion engine or rocket boosters harness this chemical explosion principle fro there working. Example also includes Trinitron toluene (TNT) and ANFO(Ammonium Nitrate Fuel oil). Detonation of condensed high explosives generates hot gases under a pressure of 300 kilo bar and temperature of about 3000 to 4000^0 Celsius . These hot gases create a spherical wave front which propagates at supersonic speed. This wave front which decreases with distance travelled is known as blast wave.

2. WAVE MECHANICS

2.1 Sound Wave

A sound wave comprises of a compression and rarefaction causing a disturbance in pressure. An idealized sound wave can be drawn as a sine wave representing disturbances in pressure. The pressure ' P' ' at any given interval 'x' is calculated using Equation (1)

$$P' = P_{max} \sin(2\Pi/\lambda).X \qquad (1)$$

Now if the wave/ disturbance is travelling with speed of sound a_0 and after time 't' the equation for P' is given as:

$$P' = P_{max} \sin(2\Pi/\lambda).(x - a_0 t) \qquad (2)$$

2.2. Shock Wave

The disturbance/ wave created by blast has a travels with supersonic speed thus creating ramping effect on surrounding. This wave front dissipates as it travels away from source.

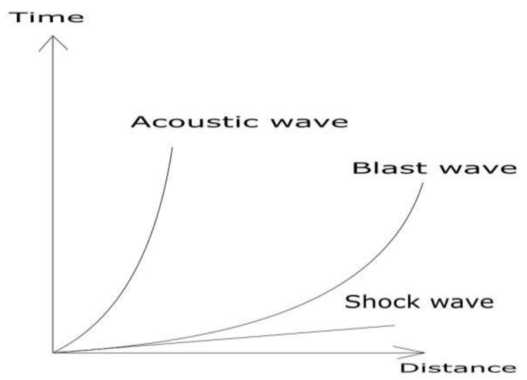

Figure 1 . Wave front comparison

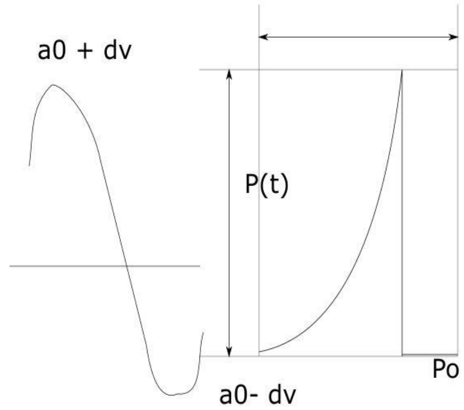

Figure 2. Blast wave front

2.3 Spherical Wave front

The sudden release of energy in atmosphere creates a pressure disturbance radiating outwards from all directions. This outward travelling disturbance creates a spherical wave front. The radius R_s of this spherical wave front for blast energy E and atmospheric density as ρ_o in time t is given by Equation :

$$R_s = C\,(E/\rho_o)^{0.25} t^{0.4} \quad (3)$$

2.4 Shock Hugoniot Equation

The relation between the conditions on both sides of a shock wave for single degree of freedom system was found out by a French engineer Pierre Henri Hugoniot. The equation is expressed in terms of specific heat ratio Υ , with a assumption that there is no heat exchange thus heat release is zero.

$$\Upsilon/(\Upsilon -1)[(P/\rho) -(P_o/\rho_o)] = 0.5\,(P - P_o)[\,(1/\rho_o) + (1/\rho)] \quad (4)$$

2.5 Curvature of Blast wave

Using shock Hugonoit and Rayleigh line equation the pressure can be associated with the velocity of blast wave. The equation uses the ratio of relative velocity of blast wave to relative velocity of acoustic wave(Mach number 'M').

$$\rho/\rho_o = (\Upsilon + 1) / (\Upsilon -1 + 2/M^2) \quad (5)$$

From Equation(5) density distribution with respect to radius of spherical disturbance r and max density and shock front ρ_s , is given as:

$$\rho(r) = \rho_s\,(r/R)^{15} \quad (6)$$

The power of equation is 15 thus implying that the curvature of blast wave is steep causing sudden exchange of energy.

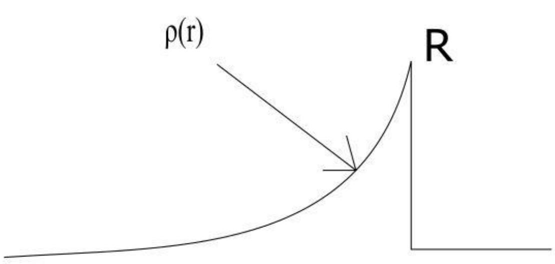

Figure 3. Blast Wave

3. BLAST WAVE SCALING

As it is difficult to create large scale explosion the overpressure caused due to such high energy blast is calculated by comparing it to experimental blast created in controlled environment. The most frequently used form of blast wave scaling is 'Hopkinson-Cranz' or ' Cube root' scaling. This law states that similar charges are produced at identical scaled distances when two explosive charges of similar geometry and of the same explosion, but of different sizes are detonated in the same atmosphere. A dimensional parameter Z is defined as scaled distance and is calculated as :

$$Z= R / E^{1/3} \tag{7}$$

or

$$Z = R / W^{1/3} \tag{8}$$

where R is the radius of spherical disturbance from source, E is total energy from detonation of explosive and W is total weight of standard explosive such as TNT.

4. PREDICTION OF OVERPRESSURE CAUSED DUE TO BLAST

Equation for calculating over pressure resulting from blast has been evolving since 1950. Following are some of the equations used for calculating over pressure based on scaled factor Z:

$$P_{so}= (6.7/Z^3) + 1 \qquad (P_{so} > 10 \text{ bar}) \tag{9}$$

$$P_{so}= (0.975/Z) + (1.455/Z^2) + (5.85/ Z^3)-0.019 \tag{10}$$

$$(0.1 \text{ bar} < P_{so} < 10 \text{ bar})$$

$$P_{so} = 6784 (W/ R^3) + 93 (W/R^3)^{0.5} \tag{11}$$

$$P_{so} = 1722/Z^3 - 144/Z^2 \tag{12}$$

And the reflected pressure P_r is calculated as:

$$P_r = 2P_{so} [(7P + 4P_{so}) / (7P + P_{so})] \tag{13}$$

Equation (9) and (10) is given by Brode(1955), (11) by Newmark and Hansen (1961), (12) by Mills (1987) and (13) by Mays and Smith (1995).

5. CASE STUDY : ALFRED P. MURRAH FEDERAL BUILDING,OKLAHOMA CITY

On 19 th of April 1995, A.P. Murrah building was targeted by terrorist. Explosive equivalent to 1800 kg of TNT was detonated using a truck parked at distance of 4 meter from the structure. The blast caused collapse of part of 9 story Murrah Building. The after math of detonation inferred that columns close to point of detonation were destroyed due to direct exposure to pressure wave where as the interior columns failed due to redistributed moment. The structure consisted of 6 main columns on exterior face, which failed under direct exposure to pressure wave. Further investigation also proved that the pressure wave created a significant amount of uplift coupled with shear force on the interior columns which in turn helped in enhancing progressive collapse. Damage investigation done by FEMA showed that 4% of structure was destroyed directly due to blast and 42 % by combined effect of blast and progressive collapse.

Figure 4. Alfred P. Murrah Federal Building

6. CONCLUSION

All important structures and high risk facilities such as public and commercial tall buildings must be designed in such a manner that they are resilient enough to dissipate significant amount of blast pressure. There are various mathematical formulations to calculate over pressure created by blast given by various researchers.

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