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RESEARCH ARTICLE OPEN ACCESS

Analysis of Structural Response under Blast Loading Using Sap 2000 and Autodyn

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ABSTRACT

The study and analysis of the explosive atmosphere in the building began in the 1960s. In the United States, the US Department of Defense released a 1959 technology textbook " Resistance to Traumatic Result" in 1959. Revised version of the brochure TM 5-1300 (1990) which is widely used by military and civil society organizations to design buildings to prevent the spread of explosions and to provide protection for personnel and critical equipment.

The following methods are available in predicting the effects of explosions on building structures e.g.

- Empirical (or analytical) methods
- Semi-empirical methods
- Number Methods

Art methods are actually related to test data. Most of these methods are limited to the basic test database level. The accuracy of all the powerful figures is reduced as the blast event approaches the field.

Semi-empirical methods, based on simple material models. An attempt to model important body processes in a simple way. These methods rely on comprehensive data and case studies. The accuracy of the guesswork is often better than that given by the construction methods. The overloading features of the event due to atomic weapons, high-powered explosives and unconventional cloud explosions are modified and followed by a description of other explosive loading features associated with air flow and display process. Fertice G. conducts extensive architecture and explosive load calculations for surface structures.

KEYWORDS- massive dynamic load, explosion-resistant structure, oxidation, blast phenomenon and unconventional cloud explosions

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I. INTRODUCTION

In recent years, explosives have been the weapon of choice in many of the terrorist attacks not only affecting human health but also the structure and integrity of the body. A bomb blast near a building can exert a tremendous amount of pressure on the building and produce high temperatures that could lead to heavy loading of the building and its contents. Such overloading can cause serious damage to the structure of the exterior and interior structure, the collapse of walls, high cost of windows, and the closure of critical health safety systems. As a result of the great impact of this massive dynamic load, efforts have been made in the last few decades to develop analytical methods and to build an explosion-resistant structure. As explosion formation is an important study topic it therefore requires a careful understanding of the explosion of effects and its effect and impact on various structural elements. The steel structure response to the explosion loading is assessed by calculating the load of the blast manually using the process and input. The reaction of the steel column depends on the amount of pressure exerted by the different charging values and the different degree of resistance to the continuous collapse of the steel is tested using Ansys Explicit dynamic and Ansys Autodyn. A concrete wall aimed at loading explosives is modeled on the Finite Element package Ansys and then analyzed by Autodyn with a metal plate and outside to study the impact of the explosion.

Content

Chemistry of Explosives

Modeling and analysis of explosive fragments requires a good understanding of chemistry because the chemical composition of the explosive source controls its properties such as speed of ripening. Explosive explosions are the product of complex physical and chemical processes inside and near the explosion and are accompanied by a rapid release of energy in the form of heat, light and sound. The chemical reactions involved in the explosion are thus oxidation as well as shocking reactions because the reactants are synthesized to provide a combination of hot gaseous products.

OXIDATION

There are two major types of oxidation reactions involved in explosions.

a) In the first type, there are two reaction components, gasoline and oxidizer, which react to the formation of explosive products.

b) A second type of reaction, consists of a single device in which the fuel and the oxidizer are contained in the same molecule, which decomposes during the reaction and is converted into oxidized products. It is very common in explosions.

Most explosives contain single molecules composed of Carbon (C), Hydrogen (H), Nitrogen (N) and Oxygen (O). These are called CHNO explosives and can be represented by the common formula $C_{cc}\ H_h\ N_{nn}\ O_{oo}$, where c, h, n, o is a carbon number, hydrogen, nitrogen, and oxygen atoms, respectively, consist of one molecule of exploding. During decomposition reaction2, the reacting molecule descends to its individual atoms next$C_{cc}\ H_h\ N_{nn}\ O_{oo}\ ,\ \rightarrow\ cC + hH + nN + oO$

These individual atoms then recombine to form the final products of the reaction. The order of reaction is

$2N \rightarrow N2$
$2H + O \rightarrow H2O$

$C + O \rightarrow CO$
$CO + O \rightarrow CO2$

If oxygen resides after the formation of carbon dioxide, that explosion is called over-oxidized. Any oxygen left behind after the formation of CO2 forms O2. However, most explosives, with the exception of nitro-glycerine and ammonium nitrate, do not have enough oxygen to convert all carbon to CO2 and these are called less oxidized explosives. In such explosives, reaction products release oxygen into the atmosphere as they grow freely. While doing so, these products combine with oxygen and can burn to produce CO2. This second reaction is part of a process known as afterburn.

The estimated amount of oxygen in the explosion is therefore an important factor in determining the nature and performance of explosive products; is expressed in the plural as an oxygen balance. The heat generated by an oxygen-free explosive (such as trinitrotoluene (TNT)) is lower than that produced by an explosive coating that completely oxidize.

Explosion and blast phenomenon

In general, an explosion is the result of a very rapid release of large amounts of energy within a limited space. Explosions can be categorized on the basis of their nature as physical, nuclear and chemical events.

In physical explosion: - Energy may be released from the catastrophic failure of a cylinder of a compressed gas, volcanic eruption or even mixing of two liquid at different temperature.

In nuclear explosion: - Energy is released from the formation of different atomic nuclei by the redistribution of the protons and neutrons within the inner acting nuclei.

In chemical explosion: - The rapid oxidation of the fuel elements (carbon and hydrogen atoms) is the main source of energy.

The type of burst mainly classified as
Air burst
High altitude burst
Under water burst Underground burst Surface burst.

Explosive and impact loads similar to and different from loads typically used in building design.

Explosive loads and impact loads are transients, or loads that are applied dynamically as one- half cycle of high amplitude, short duration air blast or contact and energy transfer related pulse. This transient load is applied only for a specific and typically short period of time in the case of blast loads, typically less than one-tenth of a second (Kirk A. Marchand, Farid Alfawakhiri (2005)). This means that an additional set of dynamic structural properties not typically considered by the designer, such as rate dependant material properties and inertial effects must be considered in design.

Often, design to resist blast, impact and other extraordinary loads must be thought of in the context of life safety, not in terms of serviceability or life-cycle performance. Performance criteria for other critical facilities (nuclear reactors, explosive and impact test facilities, etc.) may require serviceability and reuse, but most commercial office and industrial facilities will not have to perform to these levels. Structures designed to resist the effects of explosions and impact are permitted to contribute all of their resistance, both material linear and non-linear (elastic and inelastic), to absorb damage locally, so as to not compromise the integrity of the entire structure. It is likely that local failure can and may be designed to occur, due to the uncertainty associated with the loads.

BLAST WAVE SCALING LAWS

All blast parameters are primarily dependent on the amount of energy released by a detonation in the form of a blast wave and the distance from the explosion. A universal normalized description of the blast effects can be given by scaling distance relative to

$(E/Po)^{1/3}$ and scaling pressure relative to P_o, where E is the energy released (kJ) and P_o the ambient pressure (typically 100 kN/m^2). For convenience, however, it is general practice to express the basic explosive input or charge weight W as an equivalent mass of TNT. Results are then given as a function of the dimensional distance parameter,

$$\text{Scaled Distance } (Z) = \frac{R}{W^{1/3}}$$

R is the actual effective distance from the explosion.
W is generally expressed in kilograms.

Scaling laws provide parametric correlations between a particular explosion and a standard charge of the same substance.

PREDICTION OF BLAST PRESSURE

Blast wave parameter for conventional high explosive materials have been the focus of a number of studies during the 1950’ s and 1960’ s. The estimations of peak overpressure due to

spherical blast based on scaled distance $Z = \frac{R}{W^{1/3}}$

was introduced by Brode (1955) as:

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

STRUCTURAL RESPONSE TO BLAST LOADING

Complexity in analyzing the dynamic response of blast-loaded structures involves the effect of high strain rates, the non-linear inelastic material behaviour, the uncertainties of blast load calculations and the time-dependent deformations. Therefore, to simplify the analysis, a number of assumptions related to the response of structures and the loads has been proposed and widely accepted. To establish the principles of this analysis, the structure is idealized as a

single degree of freedom (SDOF) system and the link between the positive duration of the blast load and the natural period of vibration of the structure is established. This leads to blast load idealization and simplifies the classification of the blast loading regimes.

ELASTIC SDOF SYSTEMS

The simplest discretization of transient problems is by means of the SDOF approach. The actual structure can be replaced by an equivalent system of one concentrated mass and one weightless spring representing the resistance of the structure against deformation. The structural mass, M, is under the effect of an external force, $F(t)$, and the structural resistance, Rm, is expressed in terms of the vertical displacement, y, and the spring constant, K. The blast load can also be idealized as a triangular pulse having a peak force Fm and positive phase duration td.

ELASTO-PLASTIC SDOF SYSTEMS

Structural elements are expected to undergo large inelastic deformation under blast load or high velocity impact. Exact analysis of dynamic response is then only possible by step-by- step numerical solution requiring nonlinear dynamic finite- element software. However, the degree of uncertainty in both the determination of the loading and the interpretation of acceptability of the resulting deformation is such that solution of a postulated equivalent ideal elasto-plastic SDOF system (Biggs, 1964) is commonly used. Interpretation is based on the required ductility factor $\mu = y_m/y_e$. For example, uniform simply supported beam has first mode shape $\varphi(x) = \sin \pi x/L$ and the equivalent mass $M = (1/2)\, mL$, where L is the span of the beam and m is mass per Unit length.

II. BLAT LOADING ON STEEL STRUCTURE

PROBLEM DESCRIPTION

The steel framed structure which has been considered for blast loading is taken from “ Energy flow in progressive collapse of steel framed building” by Stefan Szyniszewski. This is a typical lowrise steel building in the USA. All prevailing requirements for gravity, wind, and seismic design have been considered. It was designed for a typical office occupancy live load of 2.5 kPa. The floors were assumed to support a dead load of 4 kPa, which included a concrete-steel composite slab, steel decking, ceilings/ flooring/fireproofing, mechanical/electrical/plumbing systems and partitions (1 kPa). The framing plan of the investigated 3-story building is shown in Fig. 1, Column schedules and beam designation are given in Table 1 and Table.2, respectively, with designations in accordance with AISC.

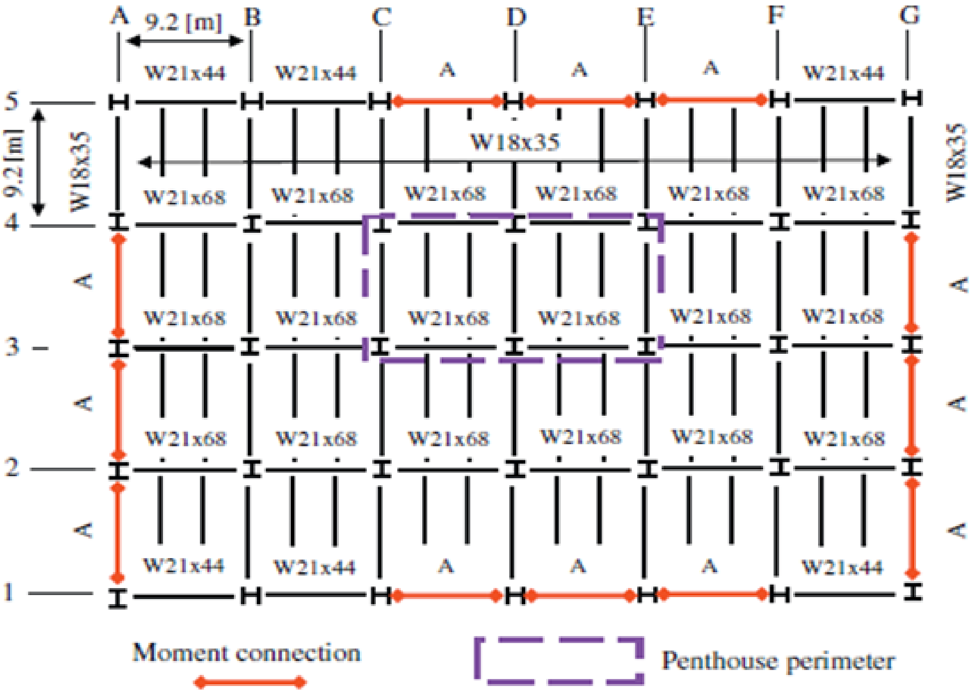

Fig 1. Framing plan of the representative steel building

Floor	2	3	Roof
Beam “A”	W18×35	W21×57	W21×62

Table.1 Beam with moment resisting connection designated with “ A”

	A	B	C	D	E	F	G
5	W12×58	W12×58	W14×74	W14×99	W14×99	W14×74	W12×58
4	W14×74	W12×58	W12×65	W12×72	W12×65	W12×58	W14×74
3	W14×99	W12×58	W12×65	W12×72	W12×65	W12×58	W14×99
2	W14×99	W12×58	W12×58	W12×58	W12×58	W12×58	W14×99
1	W14×74	W12×58	W14×74	W14×99	W14×99	W14×74	W14×74

Table.2 Steel Profile of Column

COMPUTATION OF BLAST PRESSURE

Peak Incident Pressure: The sudden increased value of the pressure on the surface due to an explosion resulting at a distance from the surface parallel to the propagation of the blast wave is called as the peak incident pressure. In Literature, various empirical relations are available to determine the pressure on the surface when the blast waves are unimpeded in its motion. Hence, the empirical relations available in literature to determine the peak incident pressure on a surface are as listed in the table below. Kinney and Graham (1985), based on the large experimental data provided the following relation to determine the peak pressure from an explosion.

Table 3. Peak Incident Pressure Calculation (Goel et al., 2012)

Kinney and Graham (1985)	$P_{\text{pos}} = P_0 \dfrac{808\left[1+\left(\dfrac{Z}{4.5}\right)^2\right]}{\left[1+\left(\dfrac{Z}{0.048}\right)^2\right]\left[1+\left(\dfrac{Z}{0.32}\right)^2\right]\left[1+\left(\dfrac{Z}{1.35}\right)^2\right]}$ (bar)
Sadovskiy (2004)	$P_{\text{pos}} = 0.085\left(\dfrac{W^{2/3}}{R}\right) + 0.3\left(\dfrac{W^{1/3}}{R}\right)^2 + 0.8\left(\dfrac{W^{1/3}}{R^2}\right)^3$ (MPa)
Bajic (2007)	$P_{\text{pos}} = 1.02\left(\dfrac{W^{1/3}}{R}\right) + 4.36\left(\dfrac{W^{2/3}}{R}\right) + 14\left(\dfrac{W}{R^3}\right)$ (bar)
Brode (1955)	$P_{\text{pos}} = \dfrac{6.7}{Z^2} + 1\text{bar}\left(P_{\text{Pos}} \geq 10 \text{ bar}\right)$
Henrych (1979)	$P_{\text{pos}} = \dfrac{0.975}{Z} + \dfrac{1.455}{Z^2} + \dfrac{5.85}{Z^3} - 0.019 \quad \left(0.1 \leq P_{\text{pos}} \geq 10 \text{ bar}\right)$ $P_{\text{pos}} = \dfrac{6.194}{Z} + \dfrac{0.326}{Z^2} + \dfrac{2.132}{Z^3} \quad \left(0.5 \leq P_{\text{pos}} \leq 1 \text{ bar}\right)$

Z = Scaled distance (m/kg$^{1/3}$)
R = Radial distance (m)
W =

Positive time duration (t_{pos}): The time difference between passing of a wave front and the end of the positive pressure phase marked by the passing of zero pressure point at a particular surface is called as the positive time duration (t_{pos}) of the blast wave. The positive time duration of a blast wave on any surface depends on the dissipation of the waves around that surface. If the surface is of small size, the positive time duration will be less as compared to a larger surface as the time required to surpass the surface will be more, hence, less dissipation possible. Many empirical relations are available in the literature to calculate the positive time duration of an explosion based on the scaled distance.

Kinney and Graham (1985)	$t_{pos} = W^{1/3} \dfrac{980\left[1+\left(\frac{Z}{0.45}\right)^{10}\right]}{\left[1+\left(\frac{Z}{0.02}\right)^{3}\right]\times\left[1+\left(\frac{Z}{0.74}\right)^{6}\right]\left[1+\left(\frac{Z}{6.9}\right)^{2}\right]}$ (msec)
Henrych (1979)	$t_{pos} = 10^{(-2.75+0.27\log_{10} Z)+\log_{10} W^{1/3}}$ (msec)

Table 4. Positive Time Duration

triangular, rectangular keeping the impulse constant. The following are the empirical relations available for calculating the impulse of a wave pressure wave.

Kinney and Graham (1985)	$I_{pos} = \dfrac{0.067\left[1+\left(\frac{Z}{0.23}\right)^{4}\right]}{Z^{2\,3}\,1+\left(\frac{Z}{1.55}\right)^{3}}$ (bar − ms)
Held (1983)	$I_{pos} = 300\dfrac{W^{2/3}}{R}$ (Pa − sec)
Sadovskiy (2004)	$I_{pos} = 200\dfrac{W^{2/3}}{R}$ (Pa − sec)

Table 5. Positive Impulse

Positive Impulse (I_{pos}): The area under the pressure-time history curve is called as impulse. The peak pressure decreases rapidly from the highest value to zero, described as quasi-exponential decrease. For simplicity, this decrease in the value of the peak pressure can be considered as triangular, rectangular keeping the impulse constant. The following are the empirical relations available for calculating the impulse of a wave pressure wave.

PEAK REFLECTED PRESSURE (P_{ref})

When a pressure wave generated from an explosion impinge a surface at an angle, it is reflected, which results in higher pressure on the surface than the incident side-on pressure. The magnitude of the reflected pressure depends on the angle of incidence of the blast wave, the radial distance of the detonation point from the surface, peak incident pressure developed due to the explosion, the type of pressure wave, and the properties of the surface. The magnitude of the reflected pressure is generally determined from the coefficient of reflection,

$P_{ref} = C_r P_{pos}$

Where C_r = Coefficient of reflection.

UFC 3-340-02 gives the detailed procedure of determining the peak reflected pressure on a surface depending upon the peak incident pressure and angle of incidence of the waves. Figure 3.3 shows the coefficient of reflection (C_r) based on the peak incident pressure of the explosion and the angle of incidence of the blast wave at a particular point on the surface.

The angle of incidence varies from 0° (wave parallel to the surface) to 90° (wave perpendicular to the surface) with the peak incident pressure.

III. CONCLUSION

It is evident from research in the literature that the limits of the explosion of pressure or pressure in the art form (Kinney and Graham's) show that it is right as explosions are complex in nature. Difficulty arises due to unexpected charging weight and stopping distance, performance of goods under different loading conditions and post blast trigerring events. Ansys Autodyn is an efficient and easy-to-use tool for simulating identity and loading effects that link it to workbench environments. The explosion simulation was carriout using the JWL as a state equivalent of explosive objects. This two-story steel structure was subordinate to the singel chargers and stand distances to obtain the same output parameters, deviations and joint response using the SAP2000. The steel column from the above structure is subject to a different charging rating and stopping distance for the parameter such as total twisting, high core pressure and very high starin and the same column is analyzed in Aotudyn to determine the continuous collapse of the steel. Concrete walls of various shapes with closed or non-closed metal plates are analyzed at Autodyn to determine the pressure layers and areas of the pressure history to study the effect of the metal application effect. From the present study look at the observations and the following conclusions.

1) The explosion of a structure causes the formation of a high reaction in the joints leading to a collapse of the joints and a complete collapse of the structure.

2) Metal column analysis in ANSYS Dynamics clear makes it clear that the effect of the explosion depends on the degree of warfare and the weight of the charge.

3) Significant twisting is achieved by high charging weight with the same standoff range as shown in the graph.

4) Higher pressures have been observed with higher charges weight then with low payloads as shown in the table and graph.

5) Completed material analysis revealed that, in axial-loaded columns, there is a critical pressure of the lateral blast. Any explosive force applied above this value will do results in the collapse of the column before the approved condition for the lowering of the beam is achieved.

6) At very high weights, falls occur quickly, as shown in the graphs. Column fails for half a time of 50 kg TNT than 20 kg TNT, and for 100 kg TNT, takes about one-fourth of failure time than 20 kg TNT.

7) In the event of a 20 kg TNT explosion, the internal power of the steel column shrinks after loading by about 0.35 ms, while no reduction in this power is observed by charging more metals than this value. This happened before the failure started.

8) With 20 kg and 50 kg charging weights, the internal power remains above the kinetic capacity until the failure starts, while at 100 kg charging weight, both energies remain the same. This may be due to the very high pressure of the heavy TNT waves.

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