OPTIMUM DESIGN OF MULTI-STORIED BUILDING AGAINST BLAST LOADS

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ABSTRACT: Apart from natural calamity, there are numerous manmade disasters that is compelling structural engineers to come up with more advancement in designing the structures. One of the biggest manmade disasters is growing terrorists'attacks. Inorder to design blast resistant building, dynamic loads must be considered as an essential parameter. The objective of this study is to understand the design theories that safeguards structure designs against the harmful effects of explosions. Firstly different types of explosions are being explained, then the detail process of explosion are illustrated for a clarity on the behavior of explosives on buildings studying the characteristics of explosion will help to design blast resistant structure in the best possible manner using requisite knowledge.

Keywords: blast resistant, dynamic load, explosives, structural response and designs

INTRODUCTION

Damage to the assets, loss of life and social panic are factors that have to be minimized if the threat of terrorist action cannot be stopped. Designing the structures to be fully blast resistant is not possible in reality anddoes not prove to be an economical one. Here with the help of engineering and architectural knowledge new as well as existing buildings can be safeguarded from the explosive effects. The aim of the study is to provide knowledge to structural engineers and spreading awareness of protection against explosions for human lives, valuables and various buildings. The blast explosion nearby or within structure is due to pressure or vehicle bomb or quarry blasting. These causes catastrophic damage to the building both externally and internally (structural frames) resulting in collapsing of walls, blowing out of windows, and shutting down of critical life-safety systems. Buildings, bridges, pipelines, industrial plants dams etc are the lifeline structures and they play an important role in the economy of the country and hence they have to be protected from dynamic and wind loading.

The study of blast effects on structures has been an area of formal technical investigation for over 60 years. A bomb explosion within or immediately nearby a building can cause catastrophic damage on the building's external and internal structural frames, collapsing of walls, blowing out of large expanses of windows, and shutting down of critical life-safety systems. Loss of life and injuries to occupants can result from many causes, including direct blast-effects, structural collapse, debris impact, fire, and smoke. The indirect effects can combine to inhibit or prevent timely evacuation, thereby contributing to additional casualties. In addition, major catastrophes resulting from gas-chemical explosions result in large dynamic loads, greater than the original design loads, of many structures.

SIGNIFICANCE

To design a blast resistant building against explosions caused by terrorist, providing protection to losses incurred due to explosives**.**

Blast Loading and Its Behavior

Explosion Science

An explosion is a rapid release of stored energy characterized by a bright flash and an audible blast. Part of the energy is released as thermal radiation (flash); and part is coupled into the air as air blast and into the soil (ground) as ground shock, both as radially expanding shock waves. To be an explosive, the material will have the following characteristics.

1. Must contain a substance or mixture of substances that remains unchanged under ordinary conditions, but undergoes a fast chemical change upon stimulation.
2. This reaction must yield gases whose volume—under normal pressure, but at the high temperature resulting from an explosion—is much greater than that of the original substance.

3. The change must be exothermic in order to heat the products of the reaction and thus to increase their pressure. Common types of explosions include construction blasting to break up rock or to demolish buildings and their foundations, and accidental explosions resulting from natural gas leaks or other chemical/explosive materials.

Effects on Structures

Blast effects on building structures can be classified as primary effects and secondary effects. Primary effects include

1. **Air blast**: the blast wave causes a pressure increase of the air surrounding a building structure and also a blast wind.
2. **Direct ground shock**: an explosive which is buried completely or partly below the ground surface will cause a ground shock. This is a horizontal (and vertical, depending on the location of the explosion with regard to the structural foundation) vibration of the ground, similar to an earthquake but with a different frequency.
3. **Heat**: a part of the explosive energy is converted to heat. Building materials are weakened at increased temperature. Heat can cause fire if the temperature is high enough.
4. **Primary fragments**: fragments from the explosive source which are thrown into the air at high velocity (for example wall fragments of an exploded gas tank). Secondary effects can be fragments hitting people or buildings near the explosion. They are not a direct threat to the bearing structure of the building, which is usually covered by a facade. However, they may destroy windows and glass facades and cause victims among inhabitants and passers-by.

Blast loading on structures can be explained by three main loading conditions (figure1)

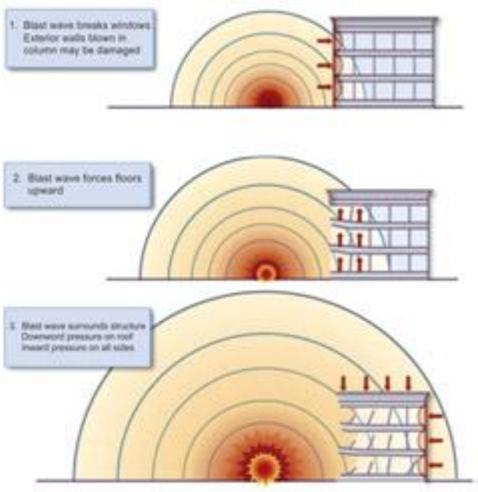

Figure 1: Blast Pressure Effects on a Structure

- In the first type a relatively large shock wave reaches a structure relatively small enough that the blast wave encloses the entire structure. The shock wave effectively acts on the entire structure simultaneously. Additionally, there is a drag force from the rapidly moving wind behind the blast wave. The structure is, however, massive enough to resist translation.
- The second condition also involves a relatively large shock wave and a target much smaller than the previous case. The same phenomena happen during this case, but the target is sufficiently small enough to be moved by the dynamic, drag pressure.
- In the final case, the shock burst is too small to surround the structure simultaneously and the structure is too large to be shifted. Instead of simultaneous loading, each component is affected in succession. For a typical building, the front face is loaded with a reflected overpressure.

LITERATURE REVIEW

In the past, few decades' considerable emphasis has been given to problems of blast and earthquake. The earthquake problem is rather old, but most of the knowledge on this subject has been accumulated during the past fifty years. The blast problem is rather new; information about the development in this field is made available mostly through publication of the Army Corps of Engineers, Department of Defense, U.S. Air Force and other governmental office and public institutes.

Much of the work is done by the Massachusetts Institute of Technology, The University of Illinois, and other leading educational institutions and engineering firms. Due to different accidental or intentional events, the behavior of structural components subjected to blast loading has been the subject of considerable research effort in recent years. Conventional structures are not designed to resist blast loads; and because the magnitudes of design loads are significantly lower than those produced by most

explosions. Further, often conventional structures are susceptible to damage from explosions. With this in mind, developers, architects and engineers increasingly are seeking solutions for potential blast situations, to protect building occupants and the structures.
This study is very much useful for design the buildings constructed for industries where chemical process is the main activity. An increasing number of research programs on the sources of these impact loads a dynamic analysis and preventive measures are being undertaken. Just in design some areas takes into account the effects of earthquakes, hurricanes, tornadoes and extremes snow loads, likewise even explosive or blast loads has to be taken into design consideration. This does not mean design and consideration of special shelter facilities but simply the application of appropriate design techniques to ordinary buildings, so that one can achieve some degree of safety from sudden attacks.

Philip Esper in 2003, after the Four major bombing incidents took place in Mainland UK within the last ten years; the 1992 St Mary's Axe, the 1993 Bishopsgate, the 1996 Docklands and Manchester bombs the author was involved in the investigation of damage and reinstatement of numerous commercial buildings, and in providing advice to building owners and occupiers on blast protection measures for both existing and proposed buildings. These detonation devices were estimated as 450 kg, 850 kg, 500 kg and 750 kg of TNT equivalent, respectively. As a result, the author was involved in the investigation of damage and reinstatement of numerous commercial buildings, and in providing advice to building owners and occupiers on blast protection measures for both existing and proposed buildings. Numerical modeling as well as laboratory and on-site testing were used in the investigation of damage and assessing the dynamic response of these buildings and their floor slabs to blast loading. The finite element (FE) analysis technique used in this investigation is described, and the correlation between the results of the FE analysis and laboratory and on-site testing is highlighted. It was concluded that the ductility and natural period of vibration of a structure governs its response to an explosion. Ductile elements, such as steel and reinforced concrete, can absorb significant amount of strain energy, whereas brittle elements, such as timber, masonry, and monolithic glass, fail abruptly.

LUCCIONI et al in 2005, studied the effects of mesh size on pressure and impulse distribution of blast loads with the aid of hydro codes. A computational dynamic analysis using AUTODYN-3D was carriedout over the congested urban environment that corresponds to the opposite rows of buildings of a block, in the same street. The results obtained for different positions of the explosive charge are presented and compared. The effect of mesh size for different boundary conditions is also addressed. It is concluded that the accuracy of numerical results is strongly dependent on the mesh size used for the analysis. On the other side the mesh size is also limited by the dimensions of the model and the computer capacity. One of the major features in the numerical simulation of blast wave propagation in large urban environments is the use of an adequate mesh size.

Ghani Razaqpur et al in 2006, investigated the behavior of reinforced concrete panels, or slabs, retrofitted with glass fiber reinforced polymer (GFRP) composite, and subjected to blast load Eight 1000 x 1000 x 70 mm panels were made of 40 MPa concrete and reinforced with top and bottom steel meshes. Five of the panels were used as control while the remaining four were retrofitted with adhesively bonded 500 mm wide GFRP laminate strips on both faces, one in each direction parallel to the panel edges. The panels were subjected to blast loads generated by the detonation of either 22.4 kg or 33.4 kg ANFO explosive charge located at a 3-m standoff. Blast wave characteristics, including incident and reflected pressures and impulses, as well as panel central deflection and strain in steel and on concrete/FRP surfaces were measured. The post-blast damage and mode of failure of each panel was observed, and those panels that were not completely damaged by the blast were subsequently statically tested to find their residual strength. It was determined that the reflected blast pressure and impulse measured at the same location during different shots using the same charge size and standoff distance were generally reasonably close, but in some cases significant deviation occurred. The results of this study indicate that the GFRP retrofit may not be suitable in every situation and that quantifying its strengthening effects will need more actual blast testing rather than merely theoretical modeling or pseudo-dynamic testing.

Ray Singh Meena in 2009, focused on the design techniques for the loading on roof structures and the resistance of open web steel joists, a common roof component. Blast loads are dynamic, impulsive and non-simultaneous over the length of a roof.

To design against explosions, a procedure has been developed to devise a uniform dynamic load on a roof that matches the response from blast loads. The objective of this research was to test and compare its results to the deflections from blast loads using FEM of analysis and to compare them to equivalent loading response. It is recommended that additional research is to be done on the prediction of blast pressures on roofs and on the development of an equivalent uniform dynamic load. It is also recommended that an analytical resistance function for open web steel joists be clearly defined, which includes all failure limit states.

Ngo ET AL in 2007, carried an analytical study on RC column subjected to blast loading and progressive collapse analysis of a multi-storied building were carried out. The 3D model of the column was analyzed using the nonlinear explicit code LS-Dyna 3D (2002) which takes into account both material nonlinearity and geometric nonlinearity. It was observed that the increase in flexural strength was greater than that of shear strength. Thus, the increase in the material strengths under dynamic conditions may lead to a shift from a ductile flexural failure to a brittle shear failure mode. In the progressive collapse analysis study which is based on the local damage assessment due to bomb blast at ground level, progressive collapse analyses was performed on the example building. The structural stability and integrity of the building were assessed by considering the effects of the failure of some perimeter columns, spandrel beams and floor slabs due to blast overpressure or aircraft impact. In addition to material and geometric nonlinearities, the analyses considered membrane action, inertia effects, and other influencing factors. The results show that the ultimate capacity of the floor slab is approximately 16.5kPa which is 2.75 times the total floor load (dead load plus 0.4 live load).

Alok Goyal in 2008, discussed through an overview to quantify blast loads as high pressure, short duration shock loading for the building as a whole and on each individual structural component. The study concluded that the most difficult part of the blast-resistance design is to define the blast wave parameters with acceptable probability of exceedance, and to quantify desired performance parameters in terms of crack widths, rotations, ductility factor capacities of elements or story drifts. Considerable efforts and skill is required to numerically predict the blast induced pressure field and highly non-linear response. Even then, the results may be meaningless due to modeling limitations and uncertainties associated with blast loads. The developed systems therefore should be tested in field and the data collected should be used to improve the design and the mathematical model.

Khadid et al., studied the fully fixed stiffened plates under the effect of blast loads to determine the dynamic response of the plates with different stiffener configurations and considered the effect of mesh density, time duration and strain rate sensitivity. He used the finite element method and the central difference method for the time integration of the nonlinear equations of motion to obtain numerical solutions.

A.K. Pandey et al.,studied the effects of an external explosion on the outer reinforced concrete shell of a typical nuclear containment structure. The analysis has been made using appropriate non-linear material models till the ultimate stages. An analytical procedure for nonlinear analysis by adopting the above model has been implemented into a finite element code DYNAIB.

Alexander M. Remennikov, studied the methods for predicting bomb blast effects on buildings. When a single building is subjected to blast loading produced by the detonation of high explosive device. Simplified analytical techniques used for obtaining conservative estimates of the blast effects on buildings. Numerical techniques including Lagrangian, Eulerian, EulerFCT, ALE, and finite element modeling used for accurate prediction of blast loads on commercial and public buildings.

J. M. Dewey, studied the properties of the blast waves obtained from the particle trajectories. First time he introduced the effect of spherical and hemispherical TNT (trinitrotoluene) in blast waves and determined the density throughout the flow by application of the Lagrangian conservation of mass equation which used for calculating the pressure by assuming the adiabatic flow for each air element between the shock fronts. The temperature and the sound speed found from the pressure and density, assuming the perfect gas equation of states.

Kirk A. Marchand et al, reviews the contents of American Institute of Steel Construction, Inc. for facts for steel buildings give a general science of blast effects with the help of numbers of case studies of the building which are damaged due to the blast loading i.e. Murrah Building, Oklahoma City, Khobar Towers, Dhahran, Saudi Arabia and others. Also studied the dynamic response of a steel structure to the blast loading and shows the behavior of ductile steel column and steel connections for the blast loads.

M. V. Dharaneepathy et al., studied the effects of the stand-off distance on tall shells of different heights, carried out with a view to study the effect of distance (ground-zero distance) of charge on the blast response. An important task in blast-resistant design is to make a realistic prediction of the blast pressures. The distance of explosion from the structure is an important datum, governing the magnitude and duration of the blast loads. The distance, known as 'critical 6 ground-zero distance', at which the blast response is a maximum. This critical distance should be used as design distance, instead of any other arbitrary distance.

METHODOLOGY

A careful study of blast waves, air shock waves and ground shock waves generated during explosion and plotting a graph with the behavior of pressure with respect to time. Blast resistant dynamic design also uses the limit state design techniques which are collapse limit design and functionality limit design. It provides sufficient ductility to the building which gives rise to the distribution of explosion energy within the structure to avoid risk of collapse.

Structural Response or Analysis to Blast Loading

Blast loading is a short duration load also called impulsive loading. Mathematically blast loading is treated as triangular loading. The ductility and natural period of vibration of a structure governs its response to an explosion.There are three kinds of explosions which are unconfined explosions, confined explosions and explosions caused by explosives attached to the structure.

Unconfined explosions can occur as an air-burst or a surface burst. In an air burst explosion, the detonation of the high explosive occurs above the ground level and intermediate amplification of the wave caused by ground reflections occurs prior to the arrival of the initial blast wave at a building (Figure 2) As the shock wave continues to propagate outwards along the ground surface, a front commonly called a Mach stem is formed by the interaction of the initial wave and the reflected wave.

However a surface burst explosion occurs when the detonation occurs close to or on the ground surface. The initial shock wave is reflected and amplified by the ground surface to produce a reflected wave. (Figure 3) Unlike the air burst, the reflected wave merges with the incident wave at the point of detonation and forms a single wave. In the majority of cases, terrorist activity occurs in built-up areas of cities, where devices are placed on or very near the ground surface.

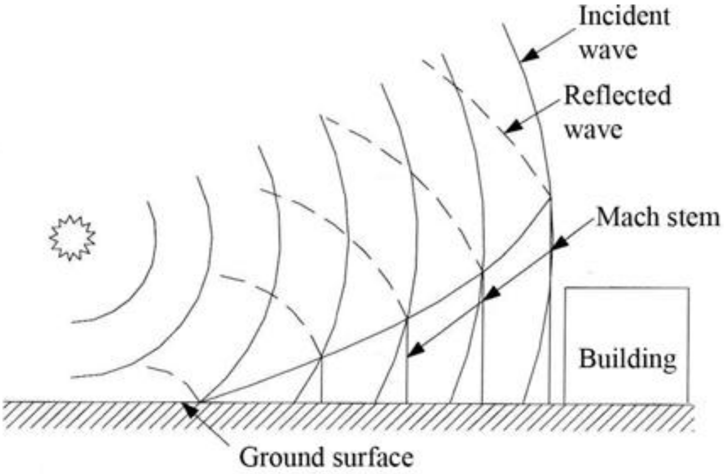

FIGURE-2 AIR BURST WITH GROUND REFLECTIONS

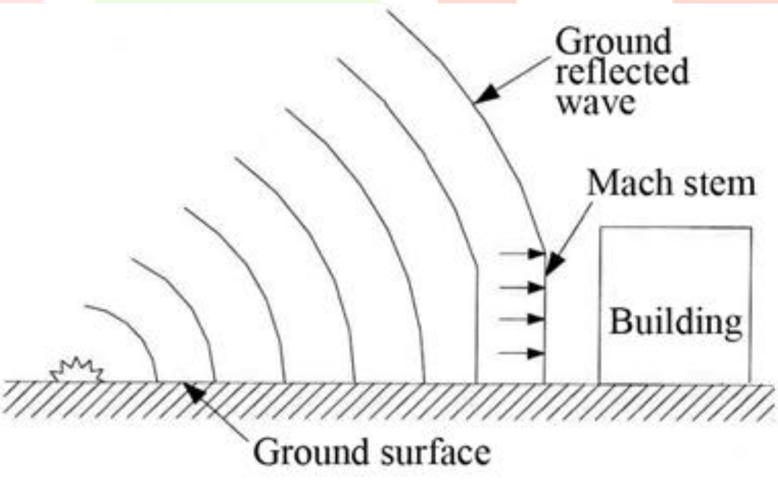

FIGURE 3 SURFACE BLAST

When an explosion occurs within a building, the pressures associated with the initial shock front will be high and therefore will be amplified by their reflections within the building. This type of explosion is called a confined explosion. In addition and depending on the degree of confinement, the effects of the high temperatures and accumulation of gaseous products produced by the chemical reaction involved in the explosion will cause additional pressures and increase the load duration within the structure. Depending on the extent of venting, various types of confined explosions are possible. (Figure 4)

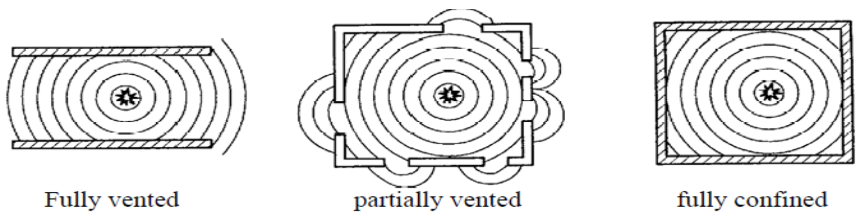

FIGURE-4 FULLY VENTED, PARTIALLY VENTED AND FULLY CONFINED EXPLOSIONS

If detonating explosive is in contact with a structural component, e.g. a column, the arrival of the detonation wave at the surface of the explosive will generate intense stress waves in the material and resulting crushing of the material. Except that an explosive in contact with a structure produces similar effects to those of unconfined or confined explosions. There are many forms of high explosive available and as each explosive has its own detonation characteristics, the properties of each blast wave will be different. TNT is being used as the standard benchmark, where all explosions can be expressed in terms of an equivalent charge mass of TNT. The most common method of equalization is based on the ratio of an explosive's specific energy to that of TNT.

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