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REVIEW PAPER ON BLAST LOADING AND IMPACT SAFE DESIGNS

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ABSTRACT

This paper's goal is to review the research that has already been done on the effects of blast loading on structures. Owing to the current rise in terrorist attacks worldwide, buildings' safety features must to be built to withstand bomb explosions. These designs can be used to create government buildings, retail centers, commercial office buildings, and even five-star hotels, even if they may be and will be economically wasteful. In essence, blast loads are dynamic loads of a kind that, like wind and seismic loads, require careful calculation. As such, structures should be designed with blast resistance in mind. However, this mindset will result in a significant increase in construction costs. Therefore, extra caution needs to be used if the building is situated in an area that is vulnerable to bombing, explosives, or conflict.

Keywords: Blast Resistant Design, Blast Load, Explosion

1. INTRODUCTION

Blast loading, also known as impulse loading, involves a brief but intense force acting on a structure. Graphically represented as a triangle, it signifies a rapid increase and decrease in load. Minimizing damage to buildings and preventing loss of life from terrorist activities remains a crucial challenge. This paper offers guidelines for mitigating explosion effects, safeguarding both structures and occupants.

Ductile materials like steel and reinforced concrete can absorb substantial strain energy, whereas brittle materials such as plain concrete, timber, brick masonry, and glass tend to fail suddenly. Existing standards, like IS4991-1968, often lack comprehensive coverage of the dynamic loads generated by bomb blasts, leaving engineers without clear design or evaluation criteria for blast anomalies. Further elucidation is necessary to address this gap.

While military circles prioritize this topic, access to pertinent test data is typically restricted. Nonetheless, various publications by US agencies offer valuable insights into blast loading. This paper delves into the literature on blast loading, elucidates special considerations in defining these loads, and explores vulnerability assessment and risk management of structures using advanced structural analysis software with nonlinear capabilities.

In the past two to three decades, significant attention has been directed towards issues related to both blasting and earthquakes. While earthquake studies have accumulated knowledge over the past fifty years, blast loading presents a distinct scenario. Recent devastating events like the Manchester Arena bombing in the UK on May 22, 2017, the Baghdad bombing in Iraq on July 3, 2016, and the coordinated terrorist attacks in Paris on November 13, 2015, among others, underscore the urgent need for thorough examination of structures under blast loads. Despite much of the relevant data being restricted to military use, there are numerous publications available from US agencies in the public domain. This paper delves into the literature on blast loading, elucidates the special conditions in defining these loads, and explores vulnerability assessment and risk management of structures using standard structural analysis software with nonlinear capabilities. With current knowledge and software, it is feasible to analyze structures exposed to blast loads and evaluate their response comprehensively.

2. LITERATUREREVIEW

1. ABS Consulting Ltd. developed the design, materials, and connections for blast-loaded structures for the Health and Safety Executive, 2006

This project involved a comprehensive review of existing methodologies and conducted dynamic analyses of various problems. A user-friendly tool, Blast STAR, was developed to analyze the blast response of structures by subjecting them to different blast pulse geometries, durations, and peak pressures. Utilizing the results of static Finite Element Analysis, Blast STAR determines force-displacement and equivalent mass characteristics of simplified equivalent systems, which are then compared with results from non-linear full model Finite Element Analysis. The analyses investigated maximum displacements for different loading scenarios across a range of structures, serving as an indicator of potential damage levels and plastic strain. Additionally, the tool calculates reaction forces at supports and forces in connections, providing valuable insights for structural assessment and comparison.

2. Assal T. Hussein's non-linear analysis of the SDOF system under blast load, 2010

The analytical methods of SDOF system analysis subject to blast loadings are presented in this paper. In order to examine the nonlinear behavior of a system, two different blast wave types were used. The analysis concentrated on the displacement time history responses, which provide the framework for examining the behavior of the SDOF System under blast loadings. There are two different kinds of blast functions: bi-linear and simple pulses. To produce time history graphs, estimated energy, and hysteresis analysis, numerous parameters have been used. The outcomes of a computer program NON-SDOF clarified the impact of blast wave type on system behavior.

3. The University of Melbourne, Australia's T. Ngo, P. Mendes, A. Gupta, and J. Ramsay, "Blast Loading and Blast Effects on Structures.", 2007

This paper highlights the persistent threat posed by terrorist organizations' use of vehicle bombs to target city centers worldwide. Such attacks can cause catastrophic damage to buildings, including structural frame failures, wall collapses, window blowouts, and critical life safety system shutdowns. Loss of life and injuries can result from various factors, including direct blast effects, structural collapse, debris impact, fire, and smoke. These events can impede timely evacuation efforts, leading to additional casualties. Furthermore, gas-chemical explosions can impose dynamic loads exceeding original design limits on structures. Consequently, over the past three decades, efforts have focused on developing structural analysis and design methods to withstand blast loads. Effective analysis and design necessitate a deep understanding of blast phenomena and the dynamic response of structural elements. This paper provides a comprehensive overview of explosion effects on structures, elucidating blast wave mechanisms and introducing methods for estimating blast loads and structural responses.

4. Impact of an External Explosion on a Concrete Structure: A Doctoral Thesis at UET Taxila, Pakistan, March 2009

The blast effects of an explosion manifest as a shock wave characterized by a high-intensity shock front that emanates outward from the explosive's surface into the surrounding air. As the wave propagates, it diminishes in strength, extends in duration, and decreases in velocity due to spherical divergence and the completion of the chemical reaction, except for residual afterburning. Approximately one-third of the chemical energy in most explosives is released during the ignition process, while the remaining two-thirds discharge gradually as detonation products mix with air and burn. This afterburning has minimal impact on the initial blast wave, occurring much slower than the detonation process. However, subsequent stages of the blast wave, especially in confined spaces, may be influenced by afterburning. As the shock wave expands, pressures decrease rapidly due to geometric divergence and energy expenditure in heating the air. Pressure levels also diminish quickly over time, with a very brief survival period measured in milliseconds. Conceptually, an explosion can be envisioned as a sphere of highly compressed air achieving equilibrium after expansion.

5. Jon A. Schmidt, P.E., "Structural Design for External Terrorist Bomb Attacks".2003

This study uses basic dynamic system models and principles to summarize the approaches that can be used to characterize an external terrorist bomb threat, estimate structural design loads, and element reactions. Building owners and designers are now more conscious of the threat posed by terrorist attacks utilizing explosives, which has increased throughout the past ten years. The US government has published several recommendations for its own facilities and supported substantial research into blast analysis and protective design techniques. The commercial sector is increasingly taking similar actions into consideration, particularly for surrounding structures that could sustain collateral damage and so-called "Icon Buildings" that are seen to be attractive targets. This article provides an overview of the approaches that can be used to identify an external terrorist bomb threat, calculate structural design loads, and determine element reactions using basic dynamic system models and concepts.

6. The impact of intense loading on reinforced concrete structures was examined by Saeed Ahmad, Mehwish Taseer, Huma Pervaiz, UET, and Taxila, 2012

This paper examines four distinct RCC walls of different thicknesses. These walls are put to the test with various explosive loads and distances. Air blast and ground shock characteristics were measured using strain gauges, data acquisition boards, accelerometers, pressure sensors, and dynamic strain amplifiers. In the end, it was said that in order to accurately analyze the structural response, air blast and ground shock pressure must be taken into account..

7. Structure and Architecture for Blast-Resistant Structures by Zeynep Koccaz, Fatih Sutcu, and Necdet Torunbalci, 2008

According to this study, the rise in terrorist acts, particularly in the last several years, has demonstrated that blast loads' detrimental effects on structures are a significant issue that needs to be taken into account throughout the design phase. Even though these attacks are rare instances of man-made disasters, blast loads are dynamic loads that require careful calculation, much like wind and earthquake loads.

This study aims to clarify ideas surrounding blast-resistant building design, improve building security against explosive impacts in the structural and architectural design processes, and provide appropriate design methodologies. First, a quick explanation of explosives and their varieties has been provided. To further explain the effects of explosives on buildings, the general aspects of the explosion process have been provided. More knowledge about explosives and explosion properties can help us design buildings that can withstand blasts much more effectively. Important methods for enhancing a building's ability to fend off explosive consequences were explored from both an architectural and structural perspective..

8. Bolt Loading Impacts on Steel Columns Aditya Kumar Tiwary, Jaypee University; Ashish Kumar Tiwary; Anil Kumar, 2015

According to this essay, a bomb explosion within or next to a building can seriously harm the structure's windows and walls on the inside in addition to its external structure. Numerous factors, including direct explosion effects, structure collapse, debris impact, fire, smoke, and others, can result in occupant injuries and fatalities. The cumulative indirect consequences may hinder or prevent prompt evacuation, leading to further casualties. In these situations, one or more of the building's columns sustain damage, which weakens the beam slab systems and eventually causes the part or the entire structure to collapse gradually.For high strain loading effects, it is necessary to investigate the columns that are prone to blast.The modal study of a steel column that was removed from a huge building frame and subjected to blast loading is presented in this paper. The implicit modal analysis was performed to evaluate the numerical model's robustness that was developed using explicit dynamic ANSYS.

9. M. R. Wakchaure and Seema T. Borole's Comparison of the Maximum Stress Distribution of the Long and Short Side Columns Due to Blast Loading, 2013

This report presents the results of a behavior research on structural concrete under blast loads. The long side and short side columns were compared, and the additional outcome was shown. This article showed the percentage of stress in the reinforced concrete column for both the long and short side columns. Eight columns on the long and short sides were the subject of a comprehensive parametric analysis to examine the effects of longitudinal reinforcement brought on by blast loading, transverse reinforcement, and finite element package. ANSYS is utilized for RC analysis. Column exposed to explosive loading.

10. Edward Eskew and Shinae Jang, "Impacts and Analysis for Buildings under Terrorist Attacks", 2012

This paper presents a methodical approach to evaluating the causes and consequences of terrorist attacks. A methodical framework for examining terrorist attacks and their effects on building structures is also provided by the literature. Typical explosive damage types to general civil structures are listed, such as the 9/11 World Trade Center attack and the Murrah Building blast. These illustrations offer insight into potential terrorist attacks. After that, the fundamentals of explosions are examined, providing the groundwork for developing analytical and experimental research. Subsequently, the effect of an explosion on a structure is examined, along with the methodology involved. Comprehensive analysis methods for a damaged building are also included, along with experimental procedures that are employed to confirm and enhance those approaches.

3. FEATURES OF BLAST LOADS

It is not appropriate to compare blast loads to seismic loads. In contrast to seismic loads, blast loads happen very quickly. As a result, material strain rate effects become an important factor to take into account while determining connection performances in the event of blast loads. However, blast loads are applied to structures on an irregular basis, therefore it is impossible to make a building both blast and earthquake proof at the same time. In contrast to seismic load intensity, blast load intensity is particularly significant for a brief period of time in a specific area or location..

4. MAJOR EFFECTS OF EXPLOSION

An explosion can have a variety of effects, including damage to neighboring buildings. Over pressurization, thermal effects, energized projectiles, debris damage, cratering, and ground shock are a few prominent causes of damage.

a. Overpressure

It is the pressure that a shock wave generates above and above the standard atmospheric pressure. This explosion is what caused the shockwave.The overpressure blast wave's size is inversely related to the receiving object's distance from the explosion's center.Both the positive and negative overpressure of the blast have the potential to cause harm to individuals as well as damage to other objects and structures. The amount of the peak overpressure, the rise time, the length, and the impulse all affect how much damage a blast wave causes. Overpressure in an enclosed space is determined by using “Weibull’s formula”

Where:

$$\Delta p = 2410\left(\frac{m}{V}\right)^{0.72}$$

- 2410isaconstant basedon1bar
- m=netexplosivemasscalculatedusingallexplosivematerialsandtheirrelativeeffectiveness
- V=volumeofgivenarea(primarilyusedtodeterminevolumewithinanenclosedspace)

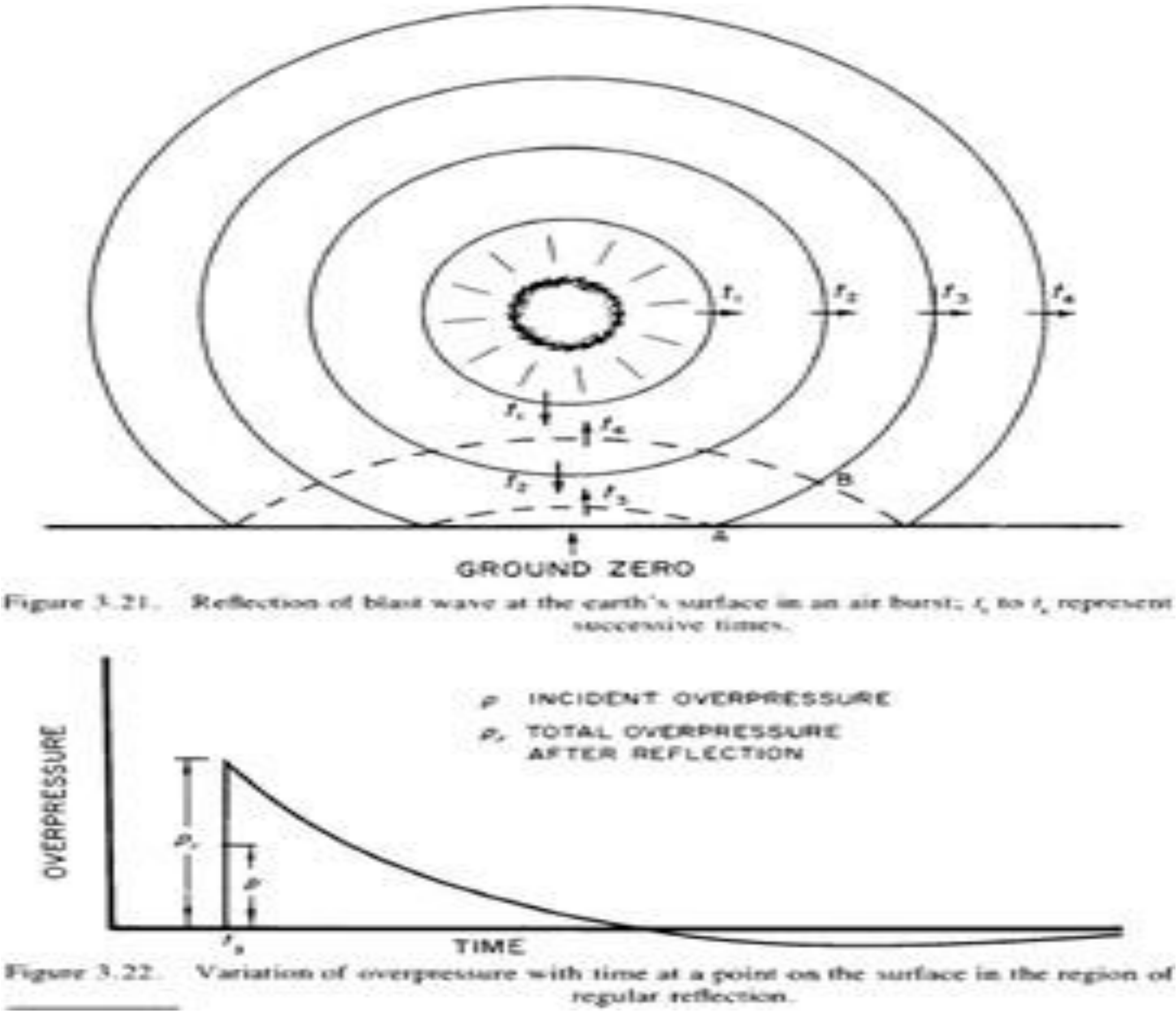

Figure 3.21. Reflection of blast wave at the earth's surface in an air burst; t_1 to t_4 represent successive times.

Figure 3.22. Variation of overpressure with time at a point on the surface in the region of regular reflection.

Figure1 GraphofOverpressure

Another significant influence is thermal impact. It happens when hot gasses build up in the form of a fireball. If a structure's fire-resisting system is damaged by the impact of a fireball and overpressure, which could knock off columns or fire coating, the extreme heat from the explosion could weaken structural parts and contribute to their failure, perhaps resulting in a localized or progressive collapse. Additionally, thermal energy has the potential to burn humans and ignite different items within a building, such furniture. The fuel mass, fireball diameter, fireball duration, and thermal emissive power all affect the fireball's strength.

b. Energized Projectiles

Energized projectiles can strike people and structures and cause considerable impact damage. They can also contain debris, shards, and missiles. Depending on the object, its closeness to the explosion, and the explosion strength, these objects are hurled by the explosion with varied degrees of force.

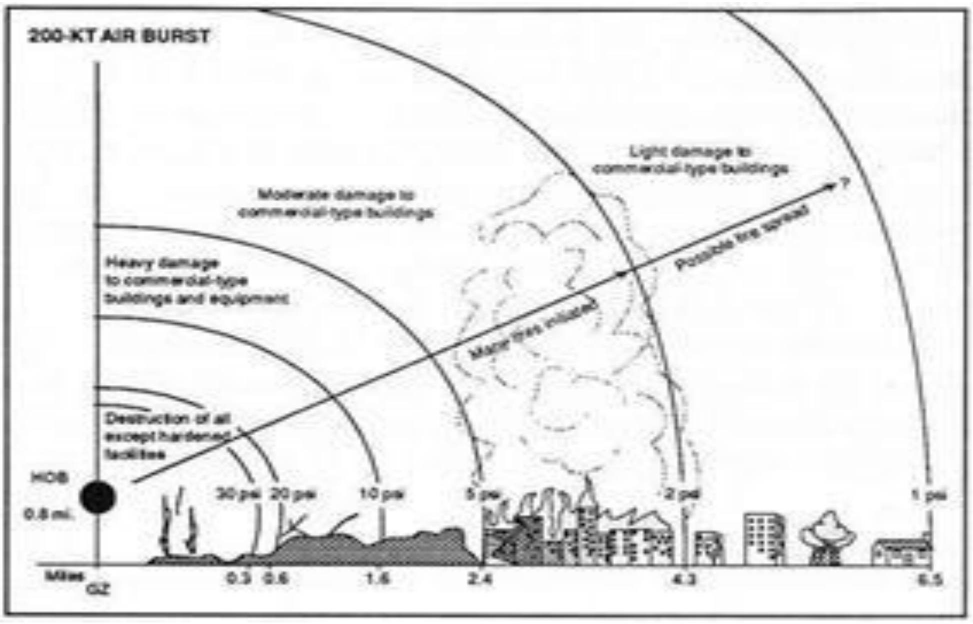

Figure2 ThermalImpactDebrisDamage

Debris and bits are hurled through the air during an explosion, seriously damaging buildings. There are two categories of fragments: primary and secondary. The primary fragments are really flung at high speeds during the explosion and are a part of the explosion container, which has a mass of about one gram. Secondary objects are things launched by the explosion that are either confined or unrestrained (such as broken windows). Their size, form, and the severity of the constraint all affect their velocity and trajectory. These items' damage depends on their speeds, the distance between their starting place and the target, the angle of incidence, and the physical characteristics of the pieces and the target.

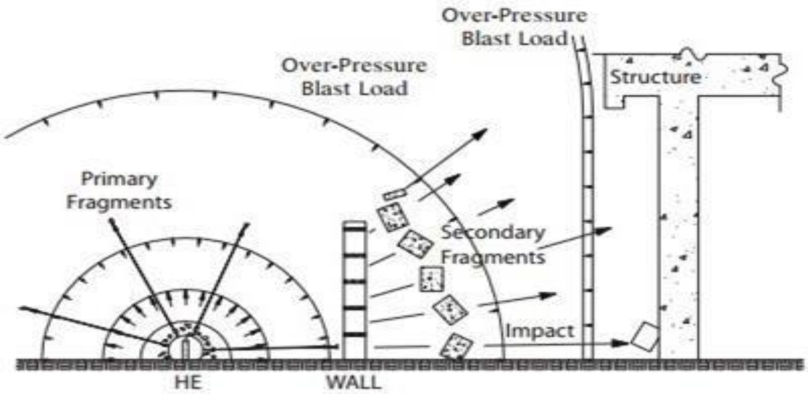

Figure3 DebrisandBrokenFragments

c. Catering & Ground Shock

This depends on where the blast occurs. Even sturdy structures can be damaged or destroyed by ground shock. When a blast occurs very near to or on the ground surface, a crater is formed. The kind of soil and the proximity of the explosion determine the crater's size..

5. PREVENTIVEPHILOSOPHY

It is not possible to design a building for an equivalent static load. During designing the philosophy that could be followed is (considering that the blast occurs outside the building):

1. Taking into account that the majority of the internal columns have a lower capacity, it is possible to remove the outer columns from the structural frame, leaving a section of the interior columns that is larger than typical. Appropriate approaches should be employed to spread the load for the absent columns.

2. The beams should be strengthened more than usual after taking into account that the outer columns have been removed. This is because, following the blast, the beams were already weak because the external columns had been demolished, which caused the load to be distributed to the internal columns.

3. Providing shear walls at appropriate intervals.

Detailing and connections

1. Employ specific seismic moment frame information.
2. . Steer clear of cuts near plastic hinges.
3. Give joints constant reinforcement.
4. Where continuous reinforcing is not possible, (especially at corners), used hooked bars.

When designing members for blast reaction, a certain level of inelastic response is typically anticipated. The selection of smaller members and the allowance of greater inelasticity enable the economy of design. Larger members are used when increased protection is necessary, possibly even to the point where there is a tendency for the design blast to become incredibly explosive. Even though the goal is elastic response, members should always have proper detailing of joints, connections, and reinforcing to enable large, inelastic deformations (thus providing greater margins against an actual blast that is larger than the design blast). Member sizes can be scaled to match the desired level of protection. It is unknown whether a structure meant for blast resistance will meet the design intent if the details are not done properly. Effective concrete detailing advice can be found in the January 2007 STRUCTURE® article Concrete Detailing for Blast.

6. CONCLUSION & FUTURE SCOPE

The primary goal is to provide the process for determining the blast loads on the structures with or without the apertures and frame structures, based on the research that are currently available in the literature. It follows that a building with a chosen safety level and a blast-resistant architectural design will obviously sustain less damage. Additionally to research the dynamic characteristics of concrete and steel reinforcement under high strain rates that are often caused by blast loads. The goal of blast-proof building design is to prevent building collapse and damage. People will have to keep searching for the most economical ways to sufficiently survive the projected blasts as better techniques are developed and put into practice. Research on blast-resistant building design is expanding quickly. Opportunities for research and development are being created by the increased demand for blast-resistant buildings. Concentrated efforts will result in the discovery of superior materials and construction methods for protective constructions.

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