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REVIEW PAPER ON BLAST LOADING AND BLAST RESISTANT STRUCTURES

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ABSTRACT

The objective of this paper is to review the works on effects of blast loading on structures that as already been done till now. Due to the recent increase in various terrorist activities all over the world, the safety of the structures should be designed to resist bomb blasts. However, these designs could be and will be economically inefficient, but they can be used for designing commercial office buildings, shopping malls, government buildings and even 5-star hotels. Blast loads are basically dynamic loads of a type that needs to be attentively calculated like wind and seismic loads and the structures should be designed by considering them to make it blast resistant. But this philosophy will cause the cost of construction to increase by a big amount. So, special care must be taken if the structure is located in a sensitive place where bombarding, explosions or war are the chiefs. Also, if it is located in the region of the high-intensity earthquake. The objectives of this study are to elucidate on blast resistant building design theories, the improvement of building security against the effects of explosives in the process of structural design and the techniques in design that should be carried out. The paper also includes information about explosives, blast loading parameters and enhancements of blast resistant building design.

Key words: Blast Resistant Design, Blast Load, Explosion

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1. INTRODUCTION

Blast loading or impulse loading is a type of load acting for a very short duration of time. Graphically, blast loading is drawn as a triangle, referring as triangular loading. Damage to the building causing loss of lives is a factor that has to be minimised if the threat of terrorist activities cannot be stopped. This paper gives guideline measures for overcoming the effects of explosions, hence providing protection to the structures and lives. Ductile elements like steel and RCC can absorb a significant amount of strain energy, whereas brittle elements like PCC, timber, brick masonry, glass, etc. fail abruptly. IS 4991-1968 has failed to deal with the different kinds of loads developed in the dynamic response of a building to bomb blast. They need further explanation as the engineers have no guidance on how to design or evaluate structures for the blast anomaly for which an elaborated understanding is required. Though this topic is of prime importance in the military circles and important data derived from tests and experiments have been restricted to army use only. Yet a number of publications are available in the public domain by the US agencies. In this paper, exploration of the literature on blast loading, explanation of special conditions in defining these loads and also the exploration of the vulnerability assessment and risk management of structures with standard structural analysis software having nonlinear capabilities. In the past 2-3 decades, substantial importance has been given to problems related to blasting and earthquake. Problems on Earthquake despite being very old, most of the knowledge on this subject has been agglomerated during the past fifty years but in the case of blast loading, this condition is different. Disasters such as Manchester Arena bombing, UK, 22nd May 2017, at the Ariana Grande's pop concert, Baghdad Bombing, Iraq, 3rd July 2016, terrorist bombings of the 13th November 2015 Paris attacks were a series of coordinated terrorist attacks in Paris and its northern Suburb, Mumbai 26/11 terrorist attack and many more have demonstrated the need for a thorough examination of the structures subjected to blast loads. With the present knowledge and software, it is possible to perform analysis of structures exposed to blast loads and to evaluate their response.

2. LITERATURE REVIEW

1. Design, materials and connections for blast-loaded structures prepared by ABS Consulting Ltd for Health and Safety Executive, 2006

This project reviewed existing methodologies and a series of dynamic analysis of a series of problems were undertaken. A simple tool for the analysis of blast response of a structure was developed. This tool, named Blast STAR, was used to carry out multiple analysis of simple structures which were loaded by blast type pulses geometries, duration and peak pressures. The tool uses the results of a static Finite Element Analysis in order to find the force- displacement and equivalent mass characteristics of an equivalent simplified system. The results of the analysis are then compared against non-linear full model Finite Element Analysis. The results explored the maximum displacements obtained for multiple loading scenarios for a range of structures. The level of displacement is indicative of the level of damage arising from a particular pulse load and can be used to predict levels of plastics strain in the structure. Calculations of the reaction forces at the supports as well as forces in the connections are also carried out and the results are compared.

2. Non-Linear Analysis of SDOF system under blast load by Assal T. Hussein, 2010

This paper presents the analytical methods of SDOF system analysis subjected to blast loadings. Two types of blast wave were applied for studying the nonlinear behaviour of a system, the analysis focused on the displacement time history responses which develop the basis for studying the behaviour of SDOF System under blast loadings. The two types of blast function are a simple pulse and bi-linear pulse. Many parameters have been used for obtaining time history plots, computed energy, and Hysteresis Analysis. The results obtained from a computer program NON-SDOF clarified the effect of type of blast wave on the behaviour of the system.

3. Blast Loading and Blast Effects on Structures by T. Ngo, P. Mendis, A. Gupta & J. Ramsay, The University of Melbourne, Australia, 2007

This paper tells the use of vehicle bombs to attack city centres has been a feature of campaigns by terrorist organisations throughout the world. A bomb explosion within or adjacent to a building can cause catastrophic damage to the building's external and internal structural frames also resulting in the 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. Due to the threat from such extreme loading conditions, efforts have been made during the past three decades to develop methods of structural analysis and design to resist blast loads. The analysis and design of structures subjected to blast loads require a detailed understanding of blast phenomena and the dynamic response of various structural elements. This paper presents a comprehensive overview of the effects of the explosion on structures. An explanation of the nature of explosions and the mechanism of blast waves in free air is given. This paper also introduces different methods to estimate blast loads and structural response.

4. Effects of an External Explosion on a Concrete Structure, PhD Thesis, UET Taxila, Pakistan, March 2009

The dissertation says that the blast effects of an explosion are in the form of a shock wave composed of a high-intensity shock front which expands outward from the surface of the explosive into the adjoining air. As the wave expands, it decays in strength, increases in duration and decreases in velocity. This phenomenon is caused by spherical divergence as well as by the fact that the chemical reaction is completed, except for some afterburning associated with the hot explosion products mixing with the surrounding atmosphere. The one-third portion of the chemical energy available in most explosives is discharged during the ignition process. The residual two-third portion is discharged slowly as the detonation products combine with air and burn. This afterburning development has a slight effect on the initial blast wave because it happens much slower than the original detonation process. On the other hand, the next stages of the blast wave can affect by the afterburning, especially for blasts in confined spaces. As the shock wave spreads out, pressures reduce quickly owing to geometric divergence and the consumption of energy in heating the air. Pressures also decrease rapidly over time and have a very short period of survival, calculated in milliseconds. An explosion can be envisaged as a sphere of extremely compressed air that attains balance after expansion.

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

This paper summarises the methods available to define an external terrorist bomb threat and estimate structural design loads and element responses using simple dynamic system models and principle. With the increase of the threat of terrorist attacks using explosives over the last decade has created an awareness of building owners and designers. The US government has funded extensive research of blast analysis and protective design methods and has produced a number of guidelines for its own facilities. The private sector is increasingly considering similar measures, especially for so-called “Icon Buildings” that are perceived to be prime targets, as well as a nearby structure that are vulnerable to collateral damage. This article summarises the methods available to define an external terrorist bomb threat and estimate structural design loads and element responses using simple dynamic system models and principles.

6. Effects of Impulsive Loading on Reinforced Concrete Structures by Saeed Ahmad, Mehwish Taseer, Huma Pervaiz, UET, Taxila, 2012

In this paper, 4 distinct RCC wall with varying thickness are taken. These walls are tested with different explosive loads and scaled distance. Pressure sensors, accelerometers, dynamic strain amplifiers, data acquisition board and strain gauges were used to measure air blast and ground shock parameters. In conclusion, it was stated that air blast and ground shock pressure must be considered for accurate analysis of structural response.

7. Architectural and Structural Design for Blast Resistant Buildings by Zeynep Koccaz, Fatih Sutcu, Necdet Torunbalci, 2008

This paper says that the increase in the number of terrorist attacks especially in the last few years has shown that the effect of blast loads on buildings is a serious matter that should be taken into consideration in the design process. Although these kinds of attacks are exceptional cases, man-made disasters; blast loads are in fact dynamic loads that need to be carefully calculated just like earthquake and wind loads.

The objective of this study is to shed light on blast resistant building design theories, the enhancement of building security against the effects of explosives in both architectural and structural design process and the design techniques that should be carried out. Firstly, explosives and explosion types have been explained briefly. In addition, the general aspects of explosion process have been presented to clarify the effects of explosives on buildings. To have a better understanding of explosives and characteristics of explosions will enable us to make blast-resistant building design much more efficiently. Essential techniques for increasing the capacity of a building to provide protection against explosive effects are discussed both with an architectural and structural approach.

8. Blast Loading Effects on Steel Columns by Ashish Kumar Tiwary, Aditya Kumar Tiwary, Anil Kumar, Jaypee University, 2015

This paper says that a bomb explosion within or adjacent to a building causes catastrophic damage to the building's exterior as well as interior structural elements including walls, windows. Loss of lives and injuries to occupants can result from many causes such as direct blast effects, structural collapse, debris impact, fire, smoke, etc. The indirect effects can combine to inhibit or prevent timely evacuation, thereby causing additional casualties. In such cases, one or more columns of the building are damaged which results in the failure of beam slab systems and thereby causing a progressive collapse of the part or the whole structure. Thus the columns which are prone to blast must be investigated for high strain loading effects. So the paper presents the modal analysis of steel column taken from a large building frame subjected to blast loading. The implicit modal analysis was done to assess the robustness of numerical model prepared in explicit dynamic ANSYS.

9. Comparison of Maximum Stress distribution of Long & Short Side Column due to Blast Loading by M. R.Wakchaure and Seema T. Borole, 2013

In this paper, a study was conducted on the behaviour of structural concrete subjected to blast loads. The comparison between long side & short side column is made & the further result was presented. In final result Percentage of Stress of Reinforced concrete column for long & short side column were presented in this paper. An extensive parametric study was carried out on a series of 8 columns at the long & short side to investigate the effect of transverse reinforcement, longitudinal reinforcement due to blast loading and finite element package ANSYS is used to analysis of RC Column subjected to blast loading.

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

This paper gives a systematic approach to assessing the causes and outcomes of terrorist attacks. The literature also provides a systematic framework to investigate terrorist attacks and their impacts on building structures. Common damage types from explosions to general civil structures are provided including the World Trade Center attack on 9/11 and the Murrah Building bombing. These examples provide perspectives on what can occur in a terrorist attack. Then the basic principles of an explosion are explored, which is the foundation to design analytical and experimental studies. After that, the impact of an explosion on a structure and how that is determined is discussed. Analysis techniques for a damaged structure are also explored in depth, as well as experimental methods used to validate and prove those techniques.

3. FEATURES OF BLAST LOADS

Blast loads cannot and should not be compared to seismic load. Unlike Seismic load, blast loads occur for a very short duration. Thus material strain rate effects become a crucial point that must be considered for defining connection performances in case of blast loads. However, it is not possible to make a building both seismic proof and blast proof at the same time and blast loads are applied on a structure irregularly. Unlike seismic load intensity, blast load intensity is of very magnitude in a particular region or space for a fraction of a second.

4 MAJOR EFFECTS OF EXPLOSION

Different types of effects can occur due to an explosion which can cause damage to the nearby building. Some major causes of damage are overpressure, thermal effects, energised projectiles, debris damage, cratering and ground shock.

a. Overpressure

It is the pressure caused by a shock wave over and above normal atmospheric pressure. This shock wave is a result of the explosion. The magnitude of overpressure blast wave is inversely proportional to the distance of the receiving object from the centre of the explosion. Damage to structures and other objects and injuries to people can be caused by both the positive and negative overpressure of the blast. The damage from a blast wave is related to the magnitude of the peak overpressure, rise time, duration, and impulse. Overpressure in an enclosed space is determined by using “Weibull’s formula”

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

Where:

- 2410 is a constant based on 1 bar
- m = net explosive mass calculated using all explosive materials and their relative effectiveness
- V = volume of given area (primarily used to determine volume within an enclosed space)

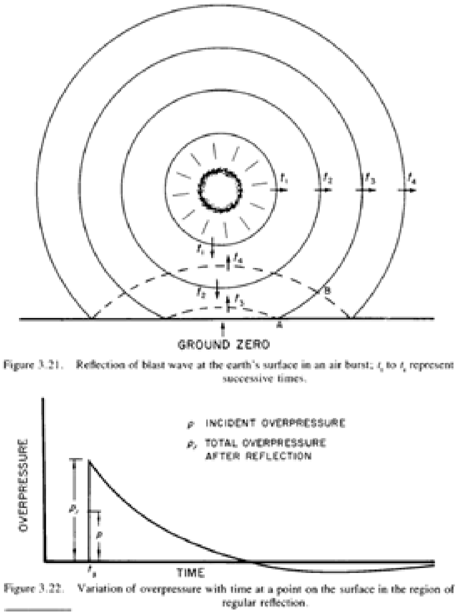

Figure 1 Graph of Overpressure

b. Thermal Effects

Thermal impact is another major effect. It occurs when a fireball, or a volume of hot gases, is generated. If the fireball impact and overpressure impact damage a structure's fire-resisting system by knocking off columns, fire coating, intense heat from the explosion can weaken structural members, which can assist in the failure of those members, leading to potential localised or progressive collapse. Thermal energy can also injure people, and ignite various objects in a structure such as a furniture. The strength of the fireball is determined by the fuel mass, fireball diameter, duration of the fireball, and the thermal emissive power.

c. Energized Projectiles

Energised projectiles consist of fragments, debris, and missiles, which can strike structures and people, causing significant impact damage. These objects are thrown by the explosion with varying levels of force depending on the object, the object's proximity to the explosion, and the explosion strength.

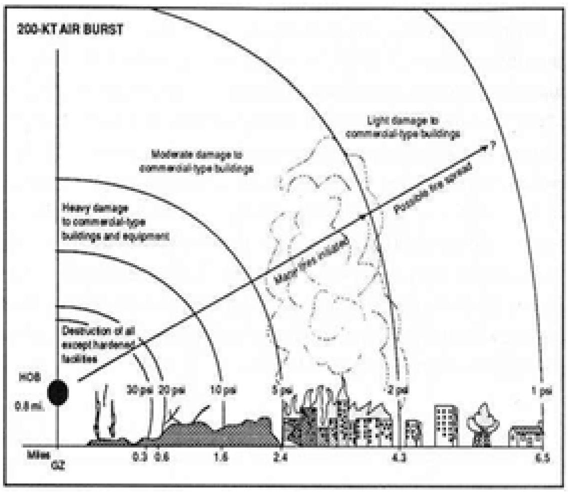

Figure 2 Thermal Impact

d. Debris Damage

When an explosion occurs, debris and fragments are thrown through the air which causes severe damage to a structure. Fragments can be classified into two types: Primary or Secondary. Primary fragments are actually parts of the explosion container having a mass of around 1 gram, which is thrown at high speeds when the explosion occurs. Secondary objects are either constrained or unconstrained objects (e.g. shards from windows) which are thrown by the explosion. Their velocity and trajectory depend on their shape, size and the strength of the constraint. The damage caused by these objects depend on their velocities, the distance between their initial location and the target, angle of incidence and physical properties of the fragments and the target.

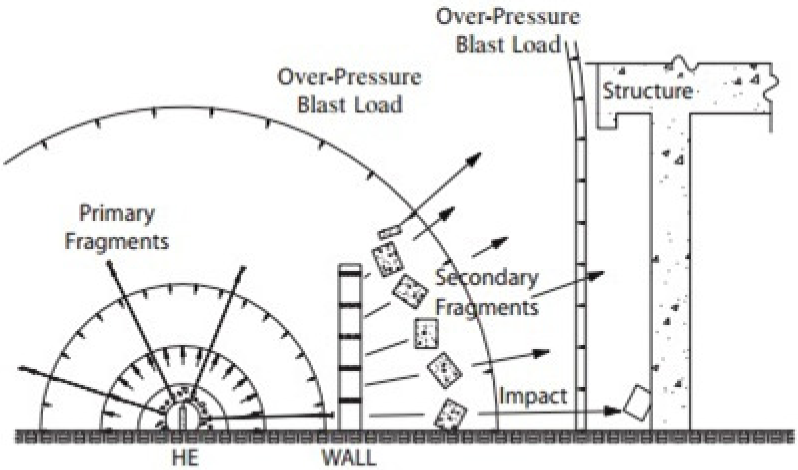

Figure 3 Debris and Broken Fragments

e. Cratering & Ground Shock

This depends on the location of the blast. Ground shock can damage or destroy even hardened structures. Crater is formed when a blast takes place very close to or on the ground surface. The size of the crater depends on the type of soil and how close the blast has occurred.

5. PREVENTIVE PHILOSOPHY

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. The exterior columns could be considered to be removed from the structural frame and considering the interior most columns having less capacity,so that the section of the interior columns are more than the usual. The load for the missing columns should be distributed by using suitable techniques
2. After considering that the exterior columns are removed, the beams should be made stronger than the usual, as after the blast, the beams are weak(due to the actual removal of the exterior columns) and hence they distribute the load to the interior columns.
3. Provision of shear walls at suitable intervals.

Detailing and connections

1. Use special seismic moment frame details.
2. Avoid splices at plastic hinge locations.
3. Provide continuous reinforcing through joints.

4. Used hooked bars where continuous reinforcing is not possible (particularly at corners).

Some amount of inelastic response is generally anticipated when designing members for blast response. The economy of design is achieved by selecting smaller members and allowing greater inelasticity. Where greater protection is warranted, larger members are selected, potentially even such that the response to the design blast threat remains elastic. While member sizes can be scaled to match the desired level of protection, proper detailing of joints, connections and reinforcing should always be provided so that the members can achieve large, inelastic deformations even if the intent is for elastic response (thus providing greater margins against an actual blast that is larger than the design blast). Without proper detailing, it is uncertain whether a structure intended for blast resistance will achieve the design intent. The January 2007 STRUCTURE® article Concrete Detailing for Blast provides effective recommendations for concrete detailing.

6. CONCLUSION & FUTURE SCOPE

Based on the studies available in the literature, the main objective is to make available the procedure for calculating the blast loads on the structures with or without the openings and frame structures. Therefore, it is obvious that a building will receive less damage with a selected safety level and a blast resistant architectural design. Also to study the dynamic properties of reinforcing steel and concrete under high strain rates typically produced by the blast loads. The aim in blast proof building design is to prevent the overall collapse of the building and damages. As improved methods are discovered and implemented, people will have to continually look for the most cost-effective ways to adequately withstand the blasts to be expected. Blast resistant building design research has been growing rapidly. The high demand for blast resistant buildings is creating opportunities for research and development. Focused efforts will lead to finding better materials and techniques to be used in the building of protective structures.

REFERENCE

[1] Indian Standard IS 4991-1968 Criteria For Blast Resistant Design Of Structures For Explosions Above Ground

[2] American Society of Civil Engineers (1997) Design of Blast Resistant Buildings in Petrochemical Facilities, Reston, VA.

[3] T. Ngo, P. Mendis, A. Gupta & J. Ramsay, Blast Loading and Blast Effects on Structures The University of Melbourne, Australia

[4] Zeynep Koccaz, Fatih Sutcu, Necdet Torunbalci, Architectural and Structural Design For Blast Resistant Buildings

[5] Design, materials and connections for blast loaded structures Prepared by ABS Consulting Ltd for the Health and Safety Executive 2006

[6] Effects of an External Explosion on a Concrete Structure PhD Thesis, UET Taxila, Pakistan, March 2009

[7] Non-Linear Analysis of SDOF System under Blast Load, Assal T. Hussein

[8] Structural Design for External Terrorist Bomb Attacks by Jon A. Schmidt, P.E.

[9] Effects of Impulsive Loading on Reinforced Concrete Structures by Saeed Ahmad, Mehwish Taseer, Huma Pervaiz, UET, Taxila, 2012

[10] Comparison of Maximum Stress distribution of Long & Short Side Column due to Blast Loading by M. R.Wakchaure and Seema T. Borole, 2013

[11] Blast Loading Effects on Steel Columns by Ashish Kumar Tiwary, Aditya Kumar Tiwary, Anil Kumar, Jaypee University, 2015

[12] Impacts and Analysis for Buildings under Terrorist Attacks by Edward Eskew & Shinae Jang, 2012

[13] A. Khadid et al. (2007), Blast loaded stiffened plates, Journal of Engineering and Applied Sciences, Vol. 2(2) pp. 456-461.

[14] Blast Resistant Design of Reinforced Concrete Structures by Dennis M. McCann, Ph.D., P.E. and Steven J. Smith, Ph.D., P.E.

[15] Hans R. W. Weibull (October 1968), Pressures recorded in partially closed chambers at explosion of TNT charges, *Annals of the New York Academy of Sciences* **152** (1) : 357-361

[16] Blast-Resistant Design Considerations by Clay Naito, PhD, P.E., Lehigh University.

[17] D. Yogeswar, Dr. C. Sashidhar, A Study on the Impact of Blast Loading for Nuclear Explosion on Structures. International Journal of Civil Engineering and Technology, 8(2), 2017, pp. 190–198.

[18] Eldo Simon and Dr. M. Sirajuddin, Parametric Study of Stand-Off Distance on a Bridge under Blast Loading. International Journal of Advanced Research in Engineering and Technology, 8(2), 2017, pp 01–07

[19] Blast resistant design of structure to terrorist explosion by Makovička D, Makovička D, Jr.

[20] Blast Resistant Building Design: Building Behavior and Key Elements by Zac Liskay, Shane Rugg, Conor Thompson

[21] https://en.wikipedia.org/wiki/Ground_burst