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Structural Analysis of Blast Resistant Building with Different Design Techniques

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***Abstract*—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. The research includes information about explosives, blast loading parameters and enhancements for blast resistant building design both with an architectural and structural approach.**

***Index Terms*—Blast Resistant structures, Stand-off distance, Blast loading, Scaled distance.**

I. INTRODUCTION

Damage to the building causing loss of lives is a factor that has to be minimized 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.

A. Blast Load

To resist blast loads, the first requirement is to determine the threat. The major threat is caused by terrorist bombings. The threat for conventional bomb is defined by two equally important elements, the bomb size, or charge weight, and stand-off distance- the minimum guarantee distance between the blast source and the target. Another requirement is to keep the bomb as far as possible, by maximizing the keep out distance. No matter what size the bomb, the damage will be less severe thefurther target from the source. Structural hardening should be actually the last resort in protecting a structure; detention and prevention must remain the first line of defence. As terrorist attacks range from the smaller letter bomb to gigantic truck bomb as experienced in the Oklahoma City, the mechanics of a conventional explosion and their effects on a target must be addressed.

II. State of Development

Literature survey related to the behaviour of structures with Blast loads was under taken to get acquainted with the latest measures and techniques adopted for the same. Technical articles published in the proceedings and other journals have been referred to determine the further scope of work and to understand the status of each project undertaken. It has been noted that many researches and academicians have worked on structural analysis of blast loaded structure.

1) Lucia Figuli et.al. (2008)

It would seem that the world is in a quiet period, because in the beginning of the century it was not a direct threat of global armed conflict. But it is not a true! The threat of terrorism resulting from religious and economic results treats the world. The terrorism is one of the gravest problems of nowadays and it is a real treat of states and people safety. The incidents, which happened not only at world battlefields of Iraq and Afghanistan but also in centers of developed countries. The assassinations of Madrid, Moscow, London, Oslo or recently of Boston brought innocent victims. Soldiers are not threatened, but they are ordinary people coming home from the work or going for culture or to do sport. This type of attacks cannot let passive anyone from democratic world. The paper deals with the analysis of structures subjected to blast load. Firstly, are mentioned the sources of blast loading. It requires to know parameters of blast pressure wave, its effect on structure and to know the tools for the solution of dynamic analysis. There is described standards and codes background used for such loaded structures.

2) Mohammed Moinuddin et.al. (2018)
In the recent years the iconic and public buildings have been the target of terrorist. Due to increase in technology the terrorist are coming up with high intensities of blasts. Arising problematic situation all over the world are bomb blast and threats. The safety of the human life against these attacks includes forecast, avoidance and variation of such events. In recent years, design and analysis of such impulsive loads subjected to structures are studied in detail to find out the performance of the structural elements subjected to sudden type of loading. It is given more importance due to the effect which is caused by blast due to high magnitude, sometimes blast may be even accidental. Thus, it is necessary to understand the effect of blast on the structure and behaviour of structural elements due the load. In present study, a seven storey reinforced concrete structure with and without bracing is considered, which is subjected to blast load of 100Kg RDX with standoff distance varying of 10m each, from 10m to 60m. The structure is analysed using SAP 2000. The blast loads is calculated using the code UFC 3-340-02. The lateral stability of the structure gives the clear effects of load on the structure. Based on the results, the effect of blast load is higher when the detonation point is closer to structure. The resistance of structure is seen when bracings are added to the structure. The structure is efficient when bracings are added to it.

3) Amol B. Unde et. al. (2013)
Terrorism is the most dangerous problem the world is facing today. It has caused the feeling of insecurity among the people despite of the advancement in technology, counterintelligence the problem remains unsolved. Despite the fact that the magnitude of the explosion and the loads caused by it cannot be anticipated perfectly efforts can be made to reduce the consequences of the explosion. Due to advancement in technology and introduction of finite elements software it is now possible to get to a reliable conclusion. 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. The study is made to understand the properties of blast wave by estimating the blast wave parameters for various charge amounts placed at various distances. The effect of TNT (trinitrotoluene) explosive on a column foundation for various amount of TNT charge at various distances is investigated for model buildings of various floors and presented in this paper.

4) Alex M Remennikov et. al. (2015)
Commercial aircraft hit both Towers 1 and 2 of the World Trade Centre (WTC) in New York on Tuesday, September 11, 2001. The aircraft had been hijacked, and the incidents caused both towers to collapse. Neighboring buildings also subsequently collapsed and there was damage over a wide area. The consequences of the September 11th tragedy will be far reaching and governments worldwide will take a closer look at the safety of infrastructure, energy supplies and buildings, as well as safety of dams and nuclear power plants The consequences of the September 11th, 2001 terrorist attack on the World Trade Centre in New York City will be far reaching for the engineering community. Government authorities worldwide are taking a closer look at the safety of infrastructure, energy supply, nuclear power plants and buildings. Civil engineers today need guidance on how to design structural systems to withstand various acts of terrorism and threats. This paper covers methods for deriving structural loadings on a building and its components in case of terrorist bombing. It briefly discusses the nature of explosions, effects of explosions on structures, and blast load-structure interaction issues. Two examples of blast load calculation for a rectangular building and a structural element are provided.

5) Kamel S. Kandil et. al. (2014)
Implicit and explicit analyses were examined with experimental work done by Razaqpur et al. In the experiment work, two 1000 × 1000 × 70 mm reinforced concrete slabs were constructed. The slabs were subjected to blast loads generated by the detonation of either 22.4 kg or 33.4 kg of ANFO located at a 3.0 m standoff. Blast wave characteristics, including incident and reflected pressures and reflected impulses were measured. The slabs were modeled by implicit and explicit analysis to study their behavior under blast load to compare their predicted and observed behavior. The post-blast damage and mode of failure of each slab were observed. It was concluded that explicit analysis provides better modeling than implicit analysis.
6) Amy Coffield et. al. (2016)
In seismic design, structural irregularity has been found to have a significant influence on structural response. The impact of structural irregularity on the global response of steel frame structures subjected to blast loading has not been examined. In the paper, six seismically designed steel framed structures are considered: moment resisting frames (MRF), concentrically braced frames (CBF) and eccentrically braced frames (EBF) each with geometric irregularity in the plan and with a geometric irregularity in the elevation. The blast loads are assumed to be unconfined, free air burst detonated 15 ft from one of the center columns. The structures are modeled and analyzed using the Applied Element Method, which allows the structure to be examined during and through structural failure. A plastic hinge analysis is performed as well as a comparative analysis observing roof deflection and acceleration to determine the effect of geometric irregularity under extreme blast loading conditions. Two different blast locations are examined. Conclusions of this research are a concentrically braced frame provides somewhat of a higher level of resistance to blast loading for irregular structures and geometric irregularity has an impact on the response of a structure subjected to blast loading.
7) Aditya C. Bhatt et. al. (2016)
The increase in the number of terrorist attacks especially in the last few years has shown that the effect of blast load on building is a serious challenge that should be taken in to consideration for designing of structures. This type of loading damages the structures, externally as well as internally. Hence the blast load should be considered with same importance as earthquake load. The present study includes the comparative performance of G+3 storey building subjected to blast and earthquake loading using ETABS. For four storey building using different input parameters like charge explosive, stand-off distance and layout of building the blast pressure are conducted and linear time history analysis is carried out. Comparative study for blast and earthquake loading is carried out for different parameters like maximum storey displacement, storey drift and quantity of materials. Safe charge explosive and safe stand-off distance are obtained for the RCC structure with the sections of structural elements same as per the requirement for earthquake resistance. Displacement is higher for the blast loading as compared to earthquake loading and very high for the storey at which blast load is applied. Quantity of concrete is 40 percentages higher for blast resistant building than the earthquake resistant building.
8) M.A. Habib et. al. (2021)
The blasts triggered by terrorist attacks and chemical detonations are imposing as the world's growing challenges as they not only effect human life, but also threaten the stability of the structure and its resilience. This paper provides comprehensive study of a reinforced concrete building under blast loading that may be triggered by terror attacks, unintended explosions, and other explosions induced by earthworks or mines. Finite element modelling was used prior to analyzing the blast phenomena on a reinforced concrete structure. The impact of blast lateral load reaction on peak deflections, story drift, and story shear was measured and compared to the combined influence of seismic and wind load on the structure. The outcomes depicted that maximum story displacement under blast loading was 87.93% higher than story displacement under combined effect of seismic and wind load, which was 136.475% for story drift and 134.976% for story shear. After providing shear wall on building, maximum story displacement under blast loading was reduced by 28.703% as compared to building exposed to blast loading without shear wall, for story drift which is about 50.2%. Due to this destructive effect of blast on structures, structures with great values must have blast resisting capacity undoubtedly.
9) Guha S. et. al. (2020)

The problem identified by research is the effects of blast loading on RCC structures. A comprehensive parametric study was conducted on RCC structure using the 3-D element model. In the analysis and design methodologies structures are subjected to blast loads with the understanding of blast phenomena and the dynamic response of various structural elements. This gives an parametric overview of the effects of blast effects on structures. Here in this paper, we are dealing with the blast force and its impact on the RCC structures. The blast pressures i.e. reflected blast pressure and overpressure have been evaluated. From this values blast forces have been evaluated. The values coming after displacement shows that as the floor height increases, deflection caused due to blast effect decreases. The result also shows relevant bending moment, shear force, axial forces. Deflection, axial force values of blast forces for charge 1500 kg at standoff distance 30 m is greater. Hence it has been concluded.

10) Chaitanya Chudiwal et. al. (2020)

A hazardous (or unstable material) is a receptive substance that contain a lot of potential vitality that can deliver a blast whenever discharged out of nowhere, normally joined by the creation of light, warmth, sound, and weight. World occasions happening in ongoing history have added to a making an open impression of the essence of expected dangers. The prime thought of frailty despite likely dangers. The prime thought in numerous examples is the explosion of a touchy gadget inside, or in the region of the structure. As of late, in light of expanded enthusiast exercises, common structure is presented to dangers from impact – initiated incautious burdens. A few such episode have occurred the world over, making genuine danger life and property. The aim of the project is to analysis and design a building to an adequate level of blast resistance. The blast explosion nearby or within structure is due to pressure or vehicle bomb or quarry blasting. These causes catastrophic damages 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 system. Buildings, bridges, pipelines, industrial plant dams etc are the life structure and they an important role in the economy of the country and hence they have to be protected from dynamic and wind loading.

III. BLAST LOAD CALCULATIONS

As Per IS:4991-1968

Determination of Blast Load

Blast Parameters

Charge Weight Considered, W=	20 0	kg	(0.1 Tonnes)
Stand Off Distance Considered=	10	m	(For Industrial Structures)

Characteristics of the Blast

Scaled Distance, X= (Actual Distance/$W^{1/3}$)

= $(20/0.2^{1/3})$

= 17.099759 m

From Table 1 of IS: 4991-1968, Assuming P_a=1kg/cm^2

P_{so}= 5.900 kg/cm^2

P_{ro} = 28.231 kg/cm^2

q_o= 6.84606 kg/cm^2

The Scaled Times for the Scaled Distance from Table 1,

t_o =	10.5499 (0.2)1/3=	x	milli seconds
t_d=	6.64 x (0.2)1/3= 3.885		milli seconds

M=Mach Number= √(1+((6/7)x(Pso/Pa))

= 2.461

a= Velocity of Sound= 344 m/sec

U= M x a	846	0.847 seconds	m/milli

Pressure on the structure

Height of the structure,H= 87.3 m

Width of the building, B= 12 m

Length of the building, L= 12 m

S= H or B/2, whichever is less= 6 m

t_c =	(3S/ U)=	21. 26	milli seconds	<t_d
t_t =	(L/ U)=	14. 17	milli seconds	<t_d

$t_r = (4S/U) = 28.35$ milliseconds $< t_d$

As tr < td, no pressure on the back face is considered

For Roof and Side Faces, Cd = -0.2

Pso+Cdqo= 4.530788 kg/cm2

IV. CONCLUSION

Structural damages caused by blast loading are the combination of both immediate effects and consecutive hazards, among which is progressive collapse. This catastrophic failure mode occurs when the initial failure of one or several key load-carrying members causes a more widespread failure of the circumventing members what leads to consummate collapse of the whole structure. The main intent of this Study is to through light on the design of blast resistant buildings and to know the response of a structure when subjected to blast loads utilizing ETABS software with prominence given on different Standoff distances of the blast and incorporating different charge weights of TNT according to the IS CODE 4991

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