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A REVIEW ON DYNAMIC ANALYSIS OF BUILDING UNDER BLAST AND SEISMIC LOADING

Pooja D. Patel[1], Hitesh K. Dhameliya[2], Krutarth S. Patel[3]

[1]*M.Tech Structural Engineering Student, CGPIT, Bardoli, Gujarat, India*
[2]*Assistant Professor Civil Engineering Department, CGPIT, Bardoli, Gujarat, India*
[3]*Assistant Professor Civil Engineering Department, CGPIT, Bardoli, Gujarat, India*

Abstract — *The aim of this study is to review the work carried out in past few years on blast effects on structures. A blast explosion inside or surrounding the structure can cause severe damage to the structural and non-structural members. The structure can be made blast resistant but not a blast proof in reality and also it is not an economical option. 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 structural design process and the design techniques that should be carried out. The paper includes introduction and detail explanation on blast wave phenomenon. Also includes review on various research on blast load and their effect on the structure studied in the past .*

Keywords*-Blast load, Seismic load, Blast Wave, Explosion, Time history analysis*

I. INTRODUCTION

Terrorist activities and threats is a growing problem nowadays around the world. Hence the concept of blast protection is found to assume an imperative part with the structural engineers. Consideration of blast load along with other dynamic loads like earthquake and wind loads is playing a vital role in the design of structures these days due to increase of terrorist activities happening since few years especially in metropolitan cities. Terrorist attacks targets where human causalities and economic consequences are likely to be substantial. Structural buildings are considered to be attracting targets because of its potential impacts and accessibility on economic activities and human lives.[1]
Blast loading is a short duration load also called impulsive loading. Mathematically blast loading is treated as triangular loading. Ductile elements, such as steel and reinforced concrete, can absorb a significant amount of strain energy, whereas brittle elements, such as timber, masonry, and monolithic glass, fail abruptly. In the investigation of the dynamic response of a building structure to bomb blast**.** In the IS 4991-1968 codes these types of loads are not dealt with and they need further elaboration as the engineers have no guidelines on how to design or evaluate structures for the blast phenomenon for which a detailed understanding is required as well as that of the dynamic response of various structural elements. There are no guidelines on such topics are given in Indian standard code also. On the other hand, this topic is the interesting one in military circles and important data derived from the experience and tests have been restricted to army use. Nevertheless, a number of publications are available in the public domain and published by the US agencies. In this paper we have explored the available literature on blast loads, explained special problems in defining these loads and explored the possibility of vulnerability assessment and risk overcoming of structures with standard structural analysis software with limited non-linear capabilities.[2]

II. BLAST WAVE PHENOMENON

Explosions occur in the form of deflagration or detonation depending on the velocity of fire during explosion. Deflagration is generated due to liberated reaction of thermal conductivity i.e., next layer of cold material is ignited by the hot burning material and burns it and so on. Detonation is a type of combustion which involves supersonic exothermic front quickening through a medium that eventually drives a shock front proliferating directly in front of it.

During detonation the hot gases that are produced expands in order to occupy the available space, leading to wave type generation through space that is transmitted spherically through the surrounding medium. As a result it causes the pressure wave to become very steep resulting in a fast travelling shock front, called explosion if subsonic and detonation if supersonic.
Fig 1 Shows the ideal blast wave pressure time-history for free air blast. Initially pressure surrounding the element is equal to the ambient pressure P_0 and it increases to P_{so} at time t_A when the shock front reach to that point. Very small time is required to reach the pressure to its peak value and it is considered zero for design purpose. P_{so} is also known as side-on overpressure or peak over pressure. The velocity of generation of shock front wave and peak over pressure decreases as it moves away from the explosion center. After its peak value pressure decreases till it reach the ambient pressure at

t_A+t_o which is known as positive phase duration. After positive phase duration the pressure becomes smaller than P_o which is known as negative phase duration.

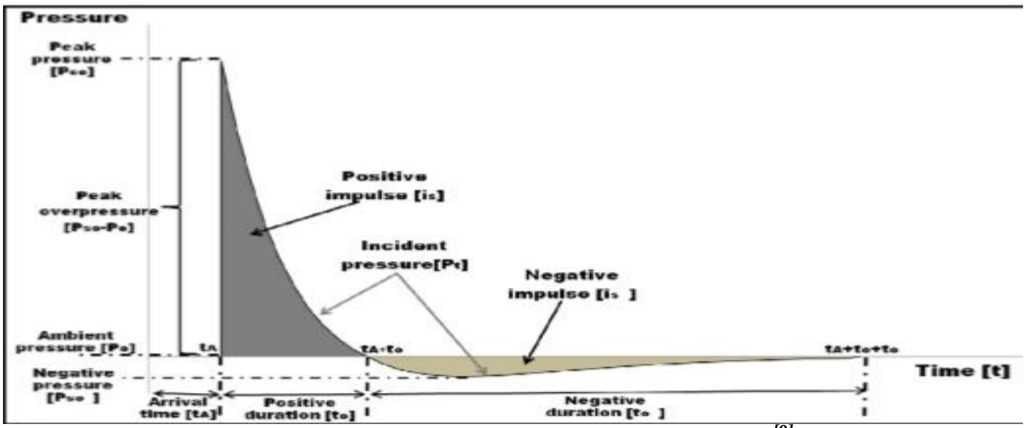

Figure 1. Ideal blast wave Pressure-Time History[9]

The negative phase of the explosive wave is usually not considered into account for design purposes as it has been verified that the main structural damage is connected to the positive phase. Additionally, the pressures that are produced from the negative phase of the blast wave are relatively small compared to those of the positive phase and since these are in the opposite direction, it is usually on the safe side to assume that they do not have a large impact on the structural integrity of structure under blast loads. However, the pressures that are below the ambient pressure value should be taken into account if the overall structural performance of a structure during a blast is assessed and not only its structural integrity.

The damage in a structure depends on the stand off distance and energy hitted on it through reflected shock front waves which is contributed by both positive and negative phase duration of time-history. Thus, while studying the response of structure under specific blast the location of explosion which produces most severe effect on the structure should be identified.

III. LITERATURE REVIEW

A. Analysis of High Rise Rcc Building Subjected to Blast Load

Jiji Madonna, Mrs. Vijaya G S, Er. Kirankumar K L[1]

In this paper the analysis of blast load for high rise building considering two variations of charge weights and standoff distance are consider. Both regular and irregular building models are prepared using ETABS software. Blast load is calculated as per procedure outlined in TM 5-1300. The software named ATBlast was developed by ARA which calculates blast load for given values of charge weights and standoff distances. It calculates blast load dynamic parameters like shock front velocity, impulse, duration and time of arrival. It was concluded that system is affected with increase in charge weight and decrease in standoff distance.

TABLE 1 BLAST LOAD PARAMETERS OF CENTRAL BAY

Storey Level	Time of arrival T_a (ms)	Load Duration T_d (ms)	Blast Pressure Psi)	Blast Load (kN)
1	2.2	1.1	1647.04	90898.33
2	3.72	1.49	655.9	36198.40
3	5.9	3.48	179.88	9927.38
4	9.32	5.9	77.08	4253.96
5	13.66	7.9	45.46	2508.89
6	18.78	9.14	32.69	1804.13
7	24.57	10.34	24.9	1374.20
8	30.88	11.57	19.62	1082.81
9	37.59	12.75	15.97	881.37
10	44.65	12.52	14.11	778.72

As per results the system was significantly affected with increase in charge weight and decrease in standoff distance. For protecting a structure standoff length is the main criteria which has an impact on the blast pressure. From graphical representation of blast pressure verses storey level, it was observed that intensity of blast pressure reduces with increase in storey height because the explosion occurs at lower storey levels, hence the pressure at this levels were high. From graphs, it’s evident that as standoff increase storey drift goes on decreasing and as charge weight increases storey drift increases. It was also observed that, the first storey columns subjected to high pressure undergoes deformation initially and there is a sudden loss of critical load bearing capacity of columns. Hence columns were failed as a result failure of building geometry takes place. The most vulnerable structure is irregular building which shows highest values of Inter-Storey drift. Because of low pressure intensity on upper floors, they were not significantly affected due to increase of standoff distance from lower floors to upper floors. Hence standoff distance would have an impact on the pressure at various floors.

B. Analysis of RCC and SIMCON Buildings Subjected to Blast Effect

Swathi Ratna K[3]

In this paper, blast analysis of multi story structure was studied. Two high rise building of Rcc and Simcon were subjected to blast effect and their fundamental frequencies were determined. Time history analysis was carried out in ETABS software. Different explosive materials release different amounts of energy per unit mass (energy density) upon detonation. The nature of the shockwave produced and the magnitude of the pressure generated from an explosion is thus dependent on the type of explosive involved. This creates a potential difficulty in blast load analysis as various explosive materials generate unique blast wave parameters in an explosion and would require knowledge of explosion behaviour and characteristics of a large number of explosives (Cooper 1994; Held 1983).Trinitrotoluene (TNT) is, therefore, used as the standard explosive to which all other explosives are compared and their equivalence to TNT established (PEC and Baker Risk 2008). TNT equivalence is used to represent the mass of TNT that will produce the same amount of energy or explosion effects as a unit mass of a particular explosive in an explosion (Sochet 2010). The investigations conducted in North Carolina University have demonstrated that a special type of continuous fiber-mat HPFRCC, called SIMCON which stands for Slurry Infiltrated Mat Concrete, is well suited for the development of novel repair, retrofit and new-construction solutions that lead to economical and improved structural performance. SIMCON uses a manufactured continuous mat of interlocking discontinuous steel fibers, placed in a form, and then infiltrated with flow able cement-based slurry. The use of continuous mats, typically made with stainless steel to control corrosion in very thin members, permits development of high flexural strengths and very high ductility with a reduced volume of fibers.
The modelling and analysis were carried out for rectangular shaped building. The rectangular building plan is shown in fig.2. All storeys were similar to ground floor plan. In that thesis, RCC and SIMCON were the two materials used for the building design. Total 12 models i.e. 6 models using RCC and 6 models using SIMCON were considered for the study.

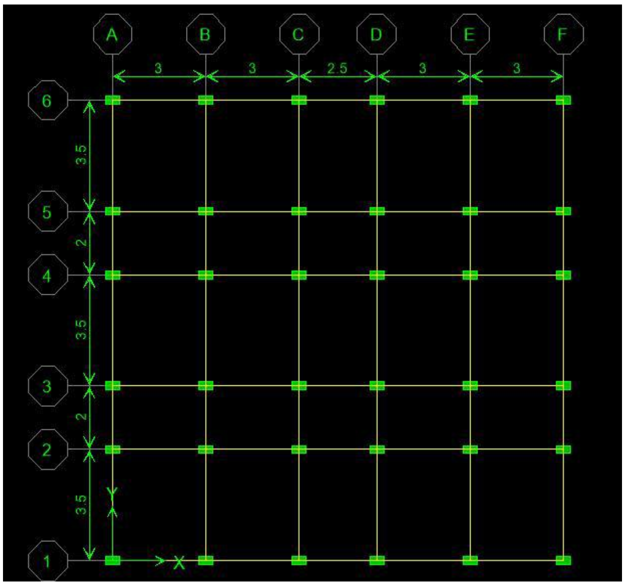

Figure 2 Rectangular Building Plan

TABLE 2 Beam Column Details

No. of Storeys	Beam Size (mm x mm)	Column Size (mm x mm)
3	250 x 350	250 x 450
5	350 x 450	350 x 350
7	350 x 450	350 x 350
9	350 x 450	350 x 350
12	400 x 450	400 x 550
15	450 x 450	450 x 600

Time history analysis was used to determine the dynamic response of a structure to arbitrary loading. ETABS can complete any number of time history cases in a single execution of the program. Each case can differ in the load applied and in the type of analysis to be performed. The pressure and time for time history analysis was calculated as per IS 4991:1968 Criteria for Blast Resistant Design OF Structures for Explosions above Ground. The time history analysis is carried out using Etabs software. The pressure versus time plot was like a triangular time history function.
It was concluded that SIMCON buildings have more fundamental frequency than RCC buildings. Overall dynamic behavior of SIMCON buildings was better than RCC buildings. As the height of SIMCON buildings increases, its frequency decreases but then also it was greater than RCC buildings. RCC buildings have greater storey displacements when compared to SIMCON buildings. The top storeys have large displacements when compared to bottom storeys. As the height of the buildings increases the storey displacements also increases but here also the displacements were less in SIMCON buildings. When standoff distance decreases then the blast effect on the building increases. But the blast effects on SIMCON buildings were comparatively less when compared to RCC buildings. The reduced displacements in SIMCON buildings subjected to blast effects shows that these structures can resist blast effects greatly than RCC buildings.

C. Earthquake Resistance and Blast Resistance :A Structural Comparision

John R. Hayes.jr, Stanley C. Woodson, Robert G. Pekelnicky, Chris D. Poland, W. Gene Corley, Mete Sozen, Michael Mahoney and Robert D. Hanson[4]

Several sources have suggested that current seismic design provisions can improve blast and progressive collapse resistance. To examine that suggestion, the Federal Emergency Management Agency (FEMA) of the U.S. Department of Homeland Security (DHS) sponsored a study at the U.S. Army Engineer Research and Development Center (ERDC). The Alfred P. Murrah Federal Building, which was severely damaged in a 1995 bombing, was hypothetically strengthened for high seismic demands. Three strengthening schemes were designed, and each strengthening scheme was then analyzed for its response to the 1995 bombing scenario. The blast and corresponding progressive collapse analyses showed that the pier-spandrel and special moment frame schemes would significantly reduce the amount of blast-induced damage and subsequent progressive collapse, compared with the response of the original building. The internal shear walls were less effective in reducing blast and progressive collapse damage. It was concluded that strengthening perimeter elements using current seismic detailing techniques improved the survivability of the building from blast loading.
The blast and progressive collapse analyses show a significant reduction in the overall severity of collapse for the schemes that strengthened the perimeter of the building – the pier-spandrel and SMF. In those systems, the collapsed area was reduced from approximately 42% of the total floor area in the 1995 bombing to an estimated 4%. The shear wall schemes more modestly improved the building response. The estimated collapsed area was reduced to an estimated 31% - 34% of the total floor area, depending on the location of the shear walls. In the original building, the blast was located away from the primary lateral load-resisting structural elements (elevator and stair core walls) and close to weaker framing elements, resulting in the greatest amount of damage. Strengthening the front wall frame resulted in the greatest blast resistance improvement. Since most fatalities in the 1995 bombing were caused by crushing injuries, any reduction in collapsed area can be expected to result in an approximately proportional reduction in casualties.
The improved response for the pier-spandrel and the SMF systems results from larger structural cross sections, increased longitudinal and transverse reinforcement, and enhanced longitudinal reinforcement continuity. The added thicknesses of the various structural elements at the lower level in the building and their increased transverse reinforcement (ties in columns, stirrups in beams) act to improve blast resistance through increasing shear and diagonal tension strength and through increasing the amount of energy that can be absorbed by the structure before it breaks up. The additional size and mass of the new members offer more inertial resistance, also permitting the elements to resist larger direct blast loads. All of the member size and reinforcement increases act to improve the flexural and shear strength of the building. The improved continuity of the longitudinal reinforcement enables the structure to be tougher and redistribute loads away from the locations where gravity support has been lost.

The shear wall schemes strengthen the building for earthquake loads, but their locations within the interior of the building leave many of the elements of the original exterior frame exposed to the bomb blast. That leaves the building to respond much as it did during the 1995 bombing. The primary gain from the shear wall schemes is the protection of the floor area behind the walls from debris generated by the blast and the ensuing collapse.

D. Blast Loading and Blast Effects on Structures- An Overview

T Ngo, P. Mendis, A. Gupta & J. Ramsay[5]

The use of vehicle bombs to attack city centers has been a feature of campaigns by terrorist organizations around the world. 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. 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 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. It was concluded that For high-risks facilities such as public and commercial tall buildings, design considerations against extreme events (bomb blast, high velocity impact) is very important. It was recommended that guidelines on abnormal load cases and provisions on progressive collapse prevention should be included in the current Building Regulations and Design Standards. Requirements on ductility levels also help improve the building performance under severe load conditions.

E. Blast Resistant Design of Structures

Vasant Matsagar, Manmohan Dass Goel[6]

The well designed and constructed structure that can exhibit improved blast resistance and at the same time maintain its architecturally appealing appearance. The blast loading, to which important structures may be subjected during their lifetime, and methods to compute it were discussed. Design criteria under blast loading for different structural members were presented as outlined in different design codes. Various blast response mitigation strategies to be incorporated at the design level were described along with the materials used. Strategies to protect against the blast were divided into two major categories: strengthening of members and protection/mitigation strategies. The emphasis herein have been protection/mitigation strategies, which include mainly increasing the standoff distance from the threat, because the blast pressure decays very rapidly and even a small distance is important. Furthermore, these mitigation measures are less expensive than the strengthening strategies. It can further be noted that the standoff distance can be increased only where sufficient space is available; however, in a city environment, many times it is not possible to adopt the strategies that require space. In such situations, the sacrificial blast wall provides a better solution and can be adopted or designed against an explosive induced threat. The various lightweight materials used for this purpose further add to increase blast resistance in comparison with conventional materials.

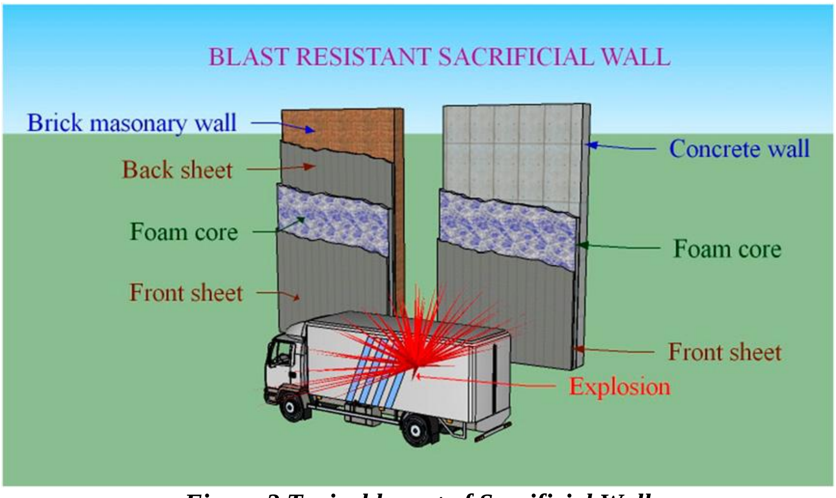

Figure 3 Typical layout of Sacrificial Wall

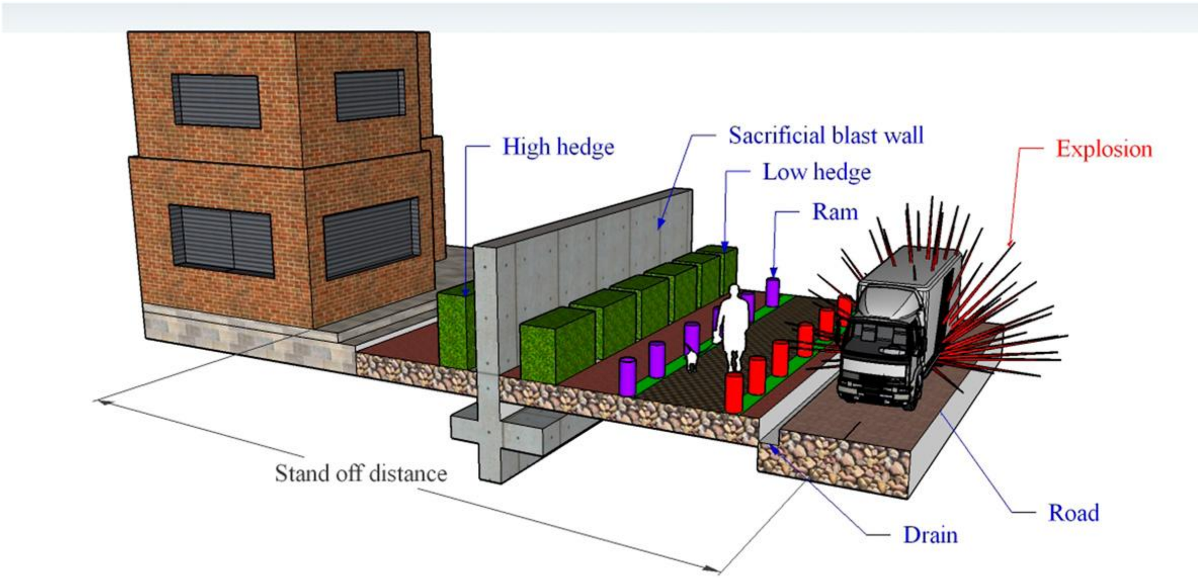

Figure 4 Different measures to enhance the protection of building against blast loading

IV. CONCLUSION

From the above literature it was concluded that

1) Structure was affected with increase in charge weight and decrease in standoff distance. Irregular buildings were vulnerable because it shows high value of inter-storey drift.
2) The fundamental frequencies of SIMCON model was greater than RCC building. Overall dynamic behaviour of SIMCON building was better than RCC building.
3) Storey displacement of RCC building was greater than SIMCON building. The blast effect was greatly resist by SIMCON building than RCC building.
4) The study suggest that proper application of current practice seismic detailing can reduce vulnerability to blast and progressive collapse.
5) The sacrificial wall provides better solution and can be adopted or designed against an explosive induced threat. The various lightweight materials used for that purpose further add to increase blast resistance in comparision with conventional materials.

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