

Behaviour of Reinforced Concrete Building Frame Subjected to Different Types of Blast Loading

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Abstract

Objectives: To assess the behaviour of reinforced concrete building frames under different types of blast loads. **Methods:** The method adopted for the analysis was ConWep blast load method. This is a computational method and is based on collection of conventional weapon effects calculations developed by U.S Dept. of Army 1998. The finite element modelling of the building was carried out by using the standard hydrocode software LS_DYNA_971 R 7.1. The charge weight was considered as 226.8 kg of TNT explosive. **Findings:** Building structures are constructed throughout the world in accordance with building codes. The available codes lack substantial design considerations to prevent or minimize the impact caused by any sort of blast. The attacks by terrorists mainly focus on the iconic buildings like school buildings, government offices and hospitals etc. which affects the safety of the structure and causes loss of lives. So before the design it is required to know the behaviour of the entire building and its critical elements to design to resist the blast loads. In this study, the material models used for the representation of concrete and steel are CSCM_CONCRETE and PIECEWISE_LINEAR_PLASTICITY respectively. The details of the modelling of building and its progressive collapse, material properties are also discussed. **Improvements:** The codes which are available for blast design are not provided the different types of failure conditions, for this reason this study was conducted and the failure conditions are observed.

Keywords: Blast Loading, Duration, Explosive Effects, Finite Element Method, Progressive Collapse, Reinforced Concrete Buildings

1. Introduction

Terrorist activities have become a threat to structures all over the world. Areas of high people concentration are becoming potential targets of bombing by these terrorists. Explosion may occur by collisions from trucks, trains, ships, helicopters or any other vehicle or gas explosions in enclosed spaces. Blast wave causes less damage than structural failure which happens as a result of those waves. Structures should be designed to resist the effects of explosions. Practical design solutions are required for the design of new buildings and the retrofitting of existing buildings to resist blast loads. Calculation of acting forces can be done according to certain blast scenario- type and weight of explosive used, the distance from the structure and the geometry of surrounding area and the structure itself. Sufficient blast resistance should be provided by

applying the relevant forces and designing the structural members, sections and connections accordingly.

In general, the load coming from the explosions is in the form of pressure. This can be analysed by using the pressure load methods or detonation simulation methods. The pressure load method (ConWep method) is a pre-programmed method which was available in the LS-DYNA software¹. During explosion rapid release of hot gases and energy takes place due to very fast chemical reaction. Very high temperatures and pressures are produced due to this reaction². The blast wave propagates through surrounding medium. The surrounding air expands in volume. Shock front or blast wave are the piled up molecules of expanded air.

Pressure of surrounding medium is initially equal to ambient pressure. It rapidly increases to a very high value of pressure known as peak over pressure. Time

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needed by blast wave to reach peak value is very small and it is considered as zero for design purposes. This value of pressure decreases with increase in distance from the centre of detonation. After reaching the peak value, the pressure decreases exponentially until it reaches the ambient temperature. This is called positive phase. Later this pressure decreases to a value lower than the ambient pressure. This is called the negative phase of Pressure-Time graph. The pressure finally becomes equal to ambient pressure as shown in Figure 1. The negative phase is not considered for design purposes because it has small effect on structural damage and value of pressure produced is small. Though it is not considered for structural integrity, it is considered when overall structural performance during blast.

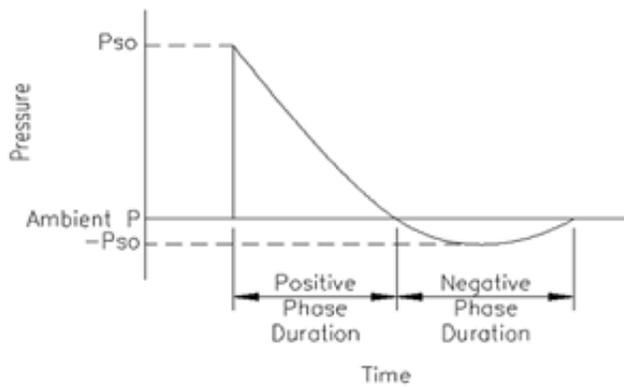


Figure 1. Pressure-time graph³.

Depending upon the relative position of centre of detonation and the height of structure to be protected above ground and the horizontal distance between explosive and structure, the blast can be classified into three types. From Figure 2 it was observed that if blast takes place in air and the blast waves hit the structure it is called free air burst. In this case the blast waves do not meet any obstacle before hitting the surface of structure. If blast takes place in air and the blast waves hit the structure it is called Air Burst. In this type of blast, the blast waves first hit the ground and then the surface of structure. These waves propagate spherically outwards. If the blast takes place almost on the ground it is called surface burst. The blast waves in this case propagate locally through the ground. These waves move outwards hemi- spherically.

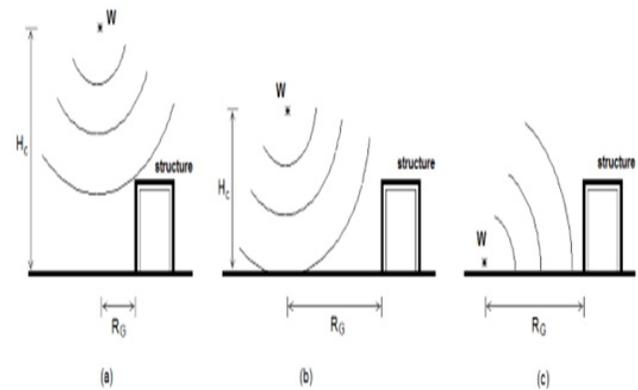


Figure 2. (a) Free Air Burst, (b) Air Burst, (c) Surface Burst⁴.

2. FEM Modeling of the Building Frame

This section comprises of details of building model including dimensions of the building frame, material properties considered and details of the frame modelling in LS-DYNA. LS-DYNA is user friendly general-purpose finite element software for numerically solving a wide variety of structural engineering problems. LS-DYNA element library consists of more than 100 different types of elements. For the numerical simulation of any RC structure, three dimensional solid elements SOLID has been used for modelling the nonlinear behaviour of concrete, three dimensional BEAM element has been used for modelling the reinforcement. The details of plan view, isometric view of full building and reinforcement model and typical beam, column and slab connection is shown in Figure 3.

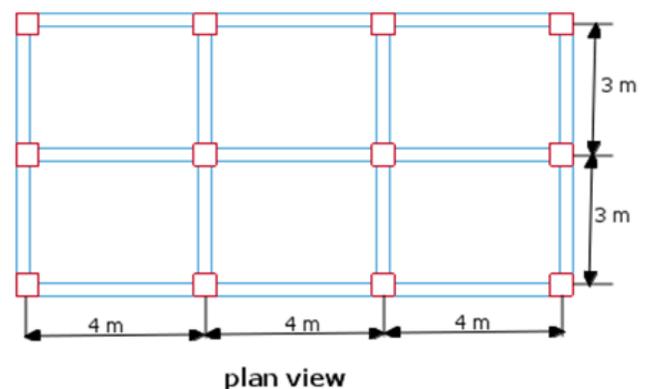


Figure 3. (a) Plan view.

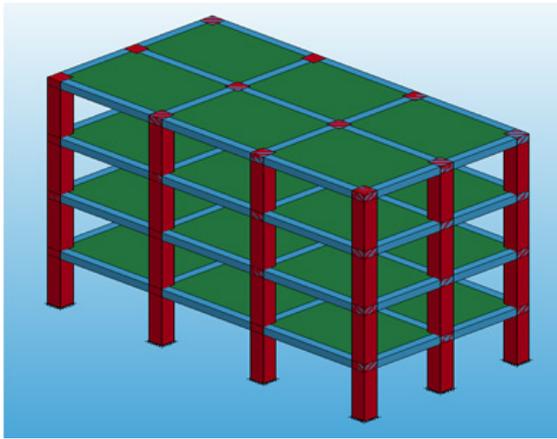


Figure 3. (b) Isometric view of the building.

The mesh elements of size 100 mm×100 mm ×100 mm, 100 mm×125 mm ×100 mm and 125 mm×100 mm× 100 mm are provided in the column, beam and slab respectively. The mesh element sizes are taken different for different parts for matching the nodes and surfaces of all the parts. This reduces the analysis time for the whole structure. The prototype building frame taken for the purpose of this study consists of two span three roomed building. The detailing of reinforcement and dimensions of beam and column are shown in Figure 4.

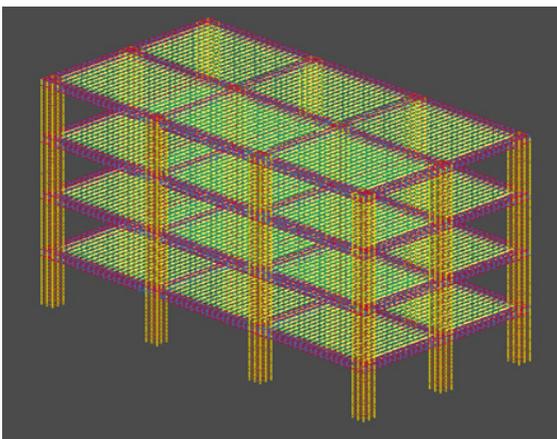


Figure 3. (c) Isometric view of the reinforcement.

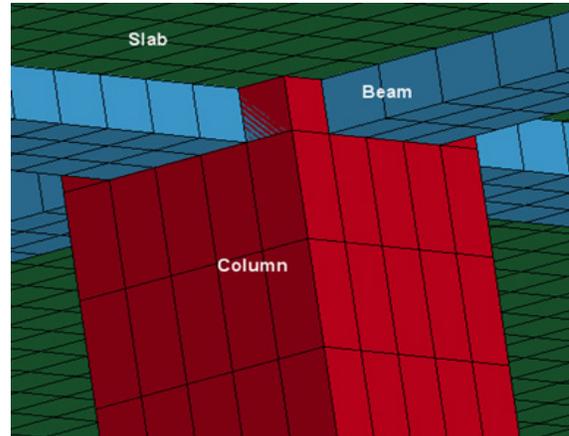


Figure 3. (d) Beam, column and slab connection.

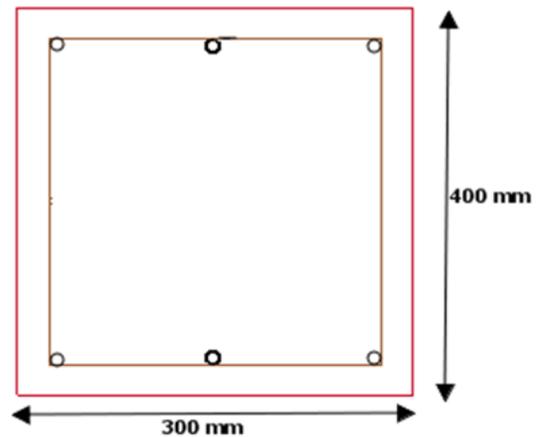


Figure 4. (a) Cross section details of the beam.

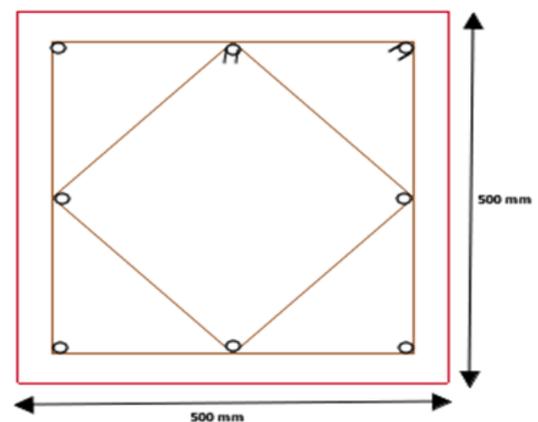


Figure 4. (b) Cross section details of the column.

Fe-415 HYSD bars are provided in the column, beam and slabs. All the reinforcement provided is modelled as beam elements and are constrained within the concrete solid. Each bar is meshed to have elements of size 0.5m. The diameter of main bars is 20mm. The diameter of distribution bars is 10mm and 12mm.

The bonding between re-bars and concrete are assigned through a constraint model known as CONSTRAINED_LAGRANGE_IN_SOLID. The material properties of steel and concrete are assigned via material card, MAT_PIECEWISE_LINEAR_PLASTICITY and CSCM_CONCRETE. The properties of concrete, steel and explosive materials are shown in the following Table 1, Table 2 and Table 3 respectively.

Table 1. Material properties of concrete

Constitutive Model	Density	Compressive strength	Poisson's ratio
CSCM_CONCRETE	2400 kg/m ³	30MPa	0.2

Table 2. Material properties of steel

Constitutive Model	Density	Yield stress	Poisson's ratio
PIECEWISE LINEAR PLASTICITY	7850 kg/m ³	415MPa	0.3

Table 3. Material properties of explosive material (TNT)

Constitutive Model	Density	Detonation velocity
LOAD_BLAST_ENHANCED	1590 kg/m ³	6930 m/s

3. Results and Discussions

The results obtained by the three types of blast loads namely free air burst, air burst and surface burst show that surface burst is most critical type of blast and results from free air burst and air burst show almost similar behaviour. In case of surface burst the concrete at the surface level erodes. The details of the results are shown in the following graphs. Figure 5 showing the variation of total energy with time in three cases of blast. And it was observed that on case of free air burst the total energy is about three times of remaining cases. Variation of lateral displacement was shown in Figure 6, and the lateral

displacement is similar in case of free air burst and air burst. Figure 7 showing the variation of velocity and it was finding that the peak velocity in free air burst and air burst was similar. Figure 8 showing the variation of acceleration along with time and the variation of pattern is similar to ideal pressure time plot. Figure 9 showing the variation of incident pressure with time and the way of pressure acting on the structure was similar in all three cases with different peak values.

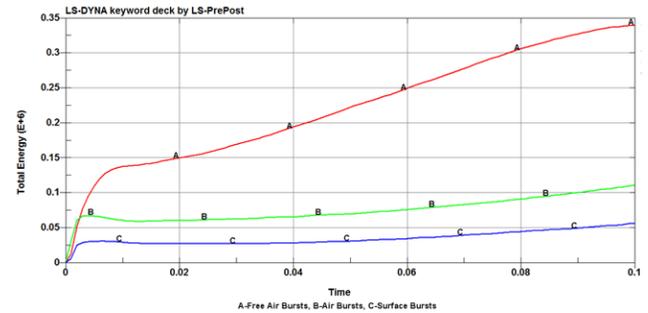


Figure 5. Comparison of the total energy verses time for three different blast loads.

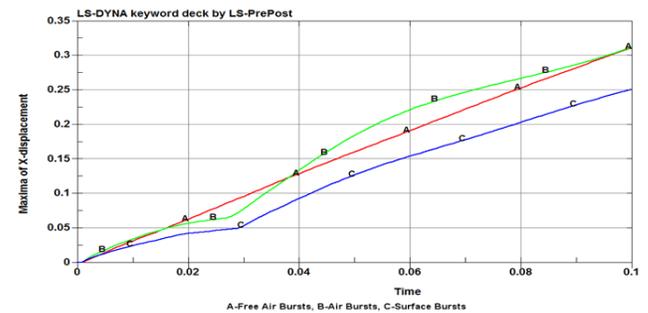


Figure 6. Comparison of the lateral displacement verses time for three different blast loads.

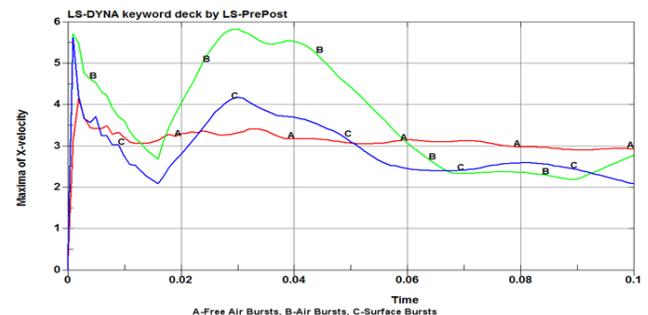


Figure 7. Comparison of the velocity verses time for three different blast loads.

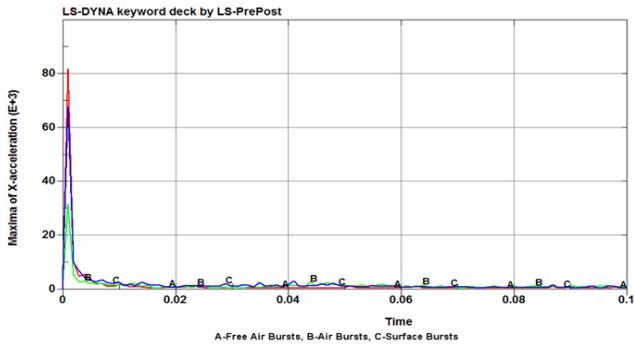


Figure 8. Comparison of the acceleration verses time for three different blast loads.

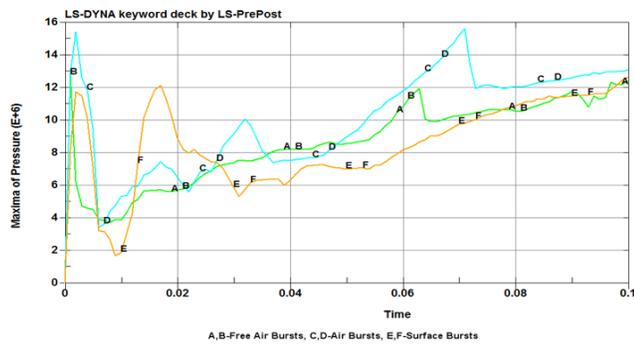


Figure 9. Comparison of the maximum pressure verses time for three different blast loads.

4. Failure Mechanisms

4.1 Erosion of Concrete at Column Base

It has been observed that the concrete near the bottom section of column which is close to blast loads, gets eroded, as shown in Figure 10(a). Strength of column material and reinforcement detailing in the bottom portion of the column are the key factors affecting the damage mechanism. Similar type failure mechanism was observed in Alaska city in 2005 as shown in Figure 10(b).

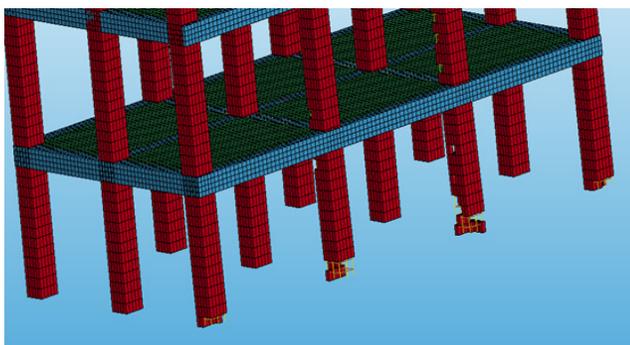


Figure 10. (a) Eroding of column bottom concrete.



Figure 10. (b) Column failure mechanisms in Alaska City (2005).

4.2 Spalling and Crushing of Concrete Surface

Concrete surfaces undergo significant amount of spalling and crushing under blast wave loads. However, there is no breakage of reinforcement bars. Figure 11(a) & Figure 11(b) shows spalling and crushing of concrete in columns. Hence, spalling of concrete is usually more severe on the back surface of a column than on the front surface facing the explosive.

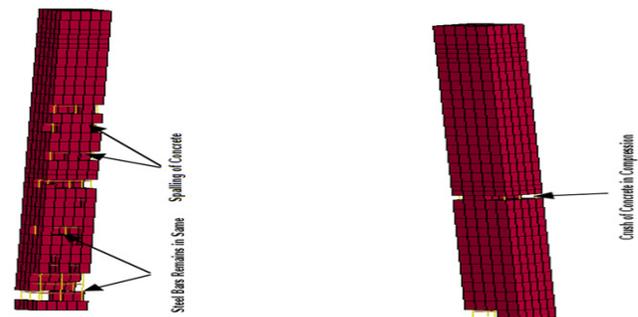
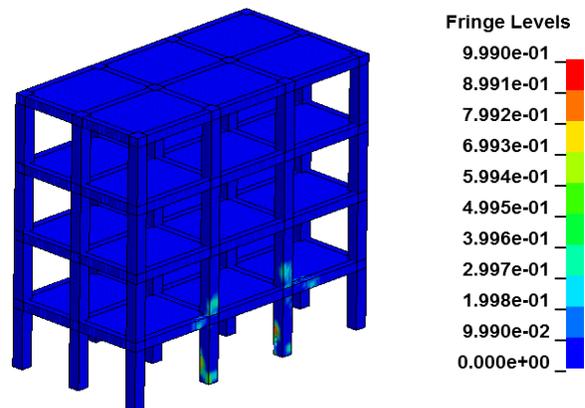


Figure 11. (a) Spalling, (b) Crushing of concrete column.



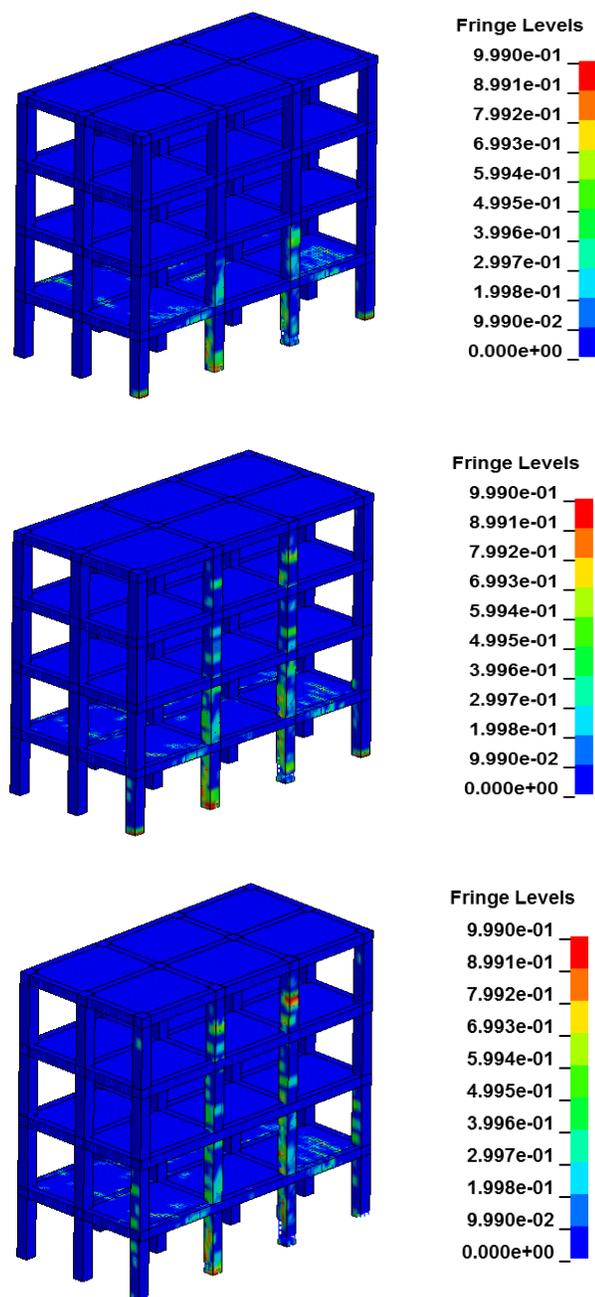


Figure 12. Variation of plastic strain with time (After 2ms, 5ms, 10ms, 25ms) in the building frame.

Figure 12 showing the variation of fringe levels at 2ms, 5ms, 10ms and 25ms. The strain levels are savour in the middle two columns because the blast was taken place in between middle two columns. And also it was identified that the pressure waves which was released from blast are also acting in the first floor slab portion and the bottom of the columns faces more pressure.

4. Conclusion

This paper gives an idea of progressive collapse of the building frame subjected to different types of blast loads namely free air bursts, air bursts and surface bursts. The model consists of four storey reinforced concrete building frame without walls. The blast has been placed at a constant distance of 2m from side face. It has been placed between two columns at the centre of the structure and for analysis of blast loads ConWep blast load method was used.

FEM method of analysis is very useful for understanding the types of failures occurring in structures and also the collapse mechanism of the whole building frame. In case of surface blast load the concrete portion at ground level was eroded more than in the other two types of blast. Similar type of failure has also been observed in case of earthquake in the Alaska city in 2005. Under this type of failure, there is a probability of collapse of the entire building.

It was observed that the lateral deflection in the columns in case of free air burst and air burst is more or less similar. Maximum value of pressure is obtained for air burst. This is because the pressure waves generated by blast are acting directly on the target structure in case of air bursts. There is large amount of spalling of concrete cover in both beams and columns and it is observed that spalling of concrete is usually more severe on the back surface of a column than on the front surface facing the explosive.

5. References

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