A comparative study of RCC frame building with infill wall for blast load wave using SAP 2000

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Abstract-*This paper presents the dynamic response of high rise building subjected to blast loading. It is about understanding the explosion phenomena and investigating the dynamic response of a concrete frame structure by using SAP2000. Building is of 4 storey is exposed to 100kg,200kg,300kg,400kg TNT. A non-linear three Dimensional is used for analyzing the dynamic response of a structure. In the present scenario, structures under blast loading (i.e. bomb explosion) are acting in short duration with high pressure intensity of shock wave which is outlined in section of TM-5 1300.The aim of this paper is to investigate the performance of high rise buildings under blast loading, blast phenomena and dynamic response of a concrete frame structure under blast loading by using SAP2000 software. The result obtained in terms of time history function, displacements and influence of the parameter considering the resistance of structure. Therefore, for decreasing the facade on surrounding buildings, moderate explosive energy is used to control the structural damages due to explosion.*

Keywords-Blasting Loading, Concrete Frame Structure, Dynamic Response, Standoff Distance, SAP 2000

I. INTRODUCTION

1.1 General

Over the last few decades considerable attention has been raised on the behavior of engineering structures under blast or impact loading. The use of explosives by terrorist groups around the world that target civilian buildings and other structures is becoming a growing problem in modern societies. Explosive devices have become smaller in size and more powerful than that's are few years ago, so it leads to increased mobility of the explosive material and also larger range effects. Usually the casualties from such a detonation are not only related to instant fatalities as a consequence of the direct release of energy, but mainly to structural failures that might occur and could result in extensive life loss.

Blasts that result from bomb explosions have become a new threat to buildings designed for normal static loads. Under blast loading, buildings are subjected to the loads that are quite different from those governing their primary design in both magnitude and direction. Thus, a better understanding of the behaviour of buildings under blast loads is of prime importance, because there are many buildings that may be under threat of blast loading although not originally designed for the same. After the events of the 11th September 2001 that led to the collapse of the World Trade Center in New York it was realized that civilian and government buildings, as well as areas with high people concentration (metro and train stations, means of mass transportation, stadiums etc.) are becoming potential bombing targets of terrorist groups.

Famous examples of such cases are the bombing attacks at the World Trade Center in 1993 and Alfred P. Murrah Federal Building in Oklahoma City in 1995.

1.2 Objective

1) To perform non-linear analysis of RCC building subjected to blast load by time history method.
2) To analyze response of building for different arrival time of blast wave.
3) To compare response of building for blast load of RCC structure with and without in fill wall in terms of displacement, velocity and acceleration

Literature Review

The analysis of the blast loading on the structure started in 1960's. US Department of the Army, released a technical manual titled ― structures to resist the effects of accidental explosions‖ in 1959. The revised edition of the manual TM 5-1300 (1990) most widely used by military and civilian organization for designing structures to prevent the propagation of explosion and to provide protection for personnel and valuable equipments. Also, IS code 4991:1968 can be used for blast resistant designing purposes. The key elements are the loads produced from explosive sources, how they interact with structures and the way structures respond to them. Explosive sources include gas, high explosives, dust and nuclear materials. The basic features of the explosion and blast wave phenomena are presented along with a discussion of TNT (trinitrotoluene) equivalency and blast scaling laws. The characteristics of incident overpressure loading due to atomic weapons, conventional high explosives and unconfined vapors cloud explosions are addressed and followed by a description of the other blast loading components associated with air flow and reflection process.

M. V. Dharaneepathy et al. (1995) studied the effects of the stand-off distance on tall shells of different heights, carried out with a view to study the effect of distance (ground-zero distance) of charge on the blast response. An important task in blast-resistant design is to make a realistic prediction of the blast pressures. The distance of explosion from the structure is an important datum, governing the magnitude and duration of the blast loads. The distance, known as ‗critical ground-zero distance', at which the blast response is a maximum. This critical distance should be used as design distance, instead of any other arbitrary distance.

Jayatilake et al. (2007) proposed response of tall buildings with symmetric setbacks under blast loading. this study explores three-dimensional nonlinear dynamic responses of typical tall buildings with and without setbacks under blast loading. The influence of the setbacks on the lateral load response due to blasts in terms of peak deflections, accelerations, inter-storey drift and bending moments at critical locations were investigated. Structural response predictions were performed with commercially available three-dimensional finite element analysis programmed using non-linear direct integration time history analyses. The response of real structures when subjected to a large dynamic input involves significant nonlinear behaviour. Dynamic inelastic analysis of three dimensional (3D) models of buildings enables more realistic assessment of their performance under unpredictable time varying, explosive loads. Inelastic behaviour is associated with hinge forming in some critical locations of the buildings. Occurrence of these hinges must be predicted and controlled in order to prevent collapse of the building. This paper reports the 3D nonlinear dynamic analyses of typical 45 storey high rise building under blast loading. This building has been designed for conventional (dead, live and wind) loads, with obvious deficiencies and vulnerabilities to blast attack. The influence of various locations of blast on the lateral load response in terms of peak deflections, accelerations, inter-storey drifts and velocity at selected locations (including hinge formation) is investigated. The component failure and structural failure of building is also determined, accordingly performance level of building is determined.

T. Ngo, et al. (2007) for their study on ―Blast loading and Blast Effects on Structures‖ gives an overview on the analysis and design of structures subjected to blast loads phenomenon for understanding the blast loads and dynamic response of various structural elements. This study helps for the design consideration against extreme events such as bomb blast, high velocity impacts.

Draganic and Sigmund (2012) have shown effect of blast loading on structures. The paper describes the process of determining the blast load on structures and provides a numerical example of a fictive structure exposed to this load. The blast load was analytically determined as a pressure-time history and numerical model of the structure was created in SAP2000. The results confirm the initial assumption that it is possible with conventional software to simulate an explosion effects and give a preliminary assessment of the structure.

Sarita Singla et al. (2015) proposed dynamic response of a space framed structure subjected to blast load'. Blast pressures for different cases are computed using correlation between blast pressure and blast scaled distance based on charts given in U.S manual. Time history loading is also obtained with parameters of reflected total over pressure and duration of positive phase of

II. BACKGROUND

Analysis of structures under blast load requires a good understanding of the blast phenomenon and a dynamic response of structural elements

2.1Explosionsand blast phenomenon

An explosion can be defined as a very fast chemical reaction involving a solid, dust or gas, during which a rapid release of hot gases and energy takes place. The phenomenon lasts only some milliseconds and it results in the production of very high temperatures and pressures. During detonation the hot gases that are produced expand in order to occupy the available space, leading to wave type propagation through space that is transmitted spherically through an unbounded surrounding medium. Along with the produced gases, the air around the blast (for air blasts) also expands and its molecules pile-up, resulting in what is known as a blast wave and shock front. The blast wave contains a large part of the energy that was released during detonation and moves faster than the speed of sound.

2.2 Ideal blast incident wave

Figure 3.1 shows the idealised profile of the pressure in relation to time for the case of a free air blast wave, which reaches a point at a certain distance from the detonation. The pressure surrounding the element is initially equal to the ambient pressure Po, and it undergoes an instantaneous increase to a peak pressure Pso at the arrival time tA, when the shock front reaches that point. The time needed for the pressure to reach its peak value is very small and for design purposes it is assumed to be equal to zero. The peak pressure Pso is also known as side-on overpressure or peak overpressure. The value of the peak overpressure as well as the velocity of propagation of the shock wave decrease with increasing distance from the detonation center. After its peak value, the pressure decreases with an exponential rate until it reaches the ambient pressure at tA+to, to being called the positive phase duration. After the positive phase of the pressure-time diagram, the pressure becomes smaller (referred to as negative) than the ambient value, and finally returns to it. The negative phase is longer than the positive one, its minimum pressure value is denoted as Pso- and its duration as to-. During this phase the structures are subjected to suction forces, which is the reason why sometimes during blast loading glass fragments from failures of facade are found outside a building instead in of inside.

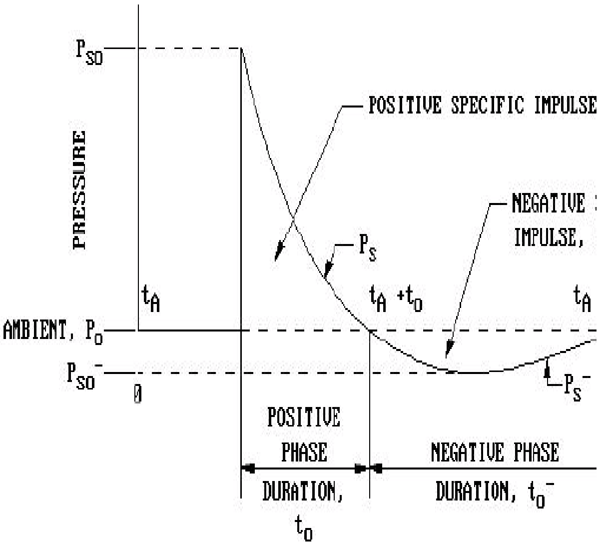


Fig.No.1 Ideal blast wave's pressure time history

The negative phase of the explosive wave is usually not taken 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 big impact on the structural integrity of buildings 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 building during a blast is assessed and not only its structural integrity. As can be seen from Figure 3.1, the positive incident pressure decreases exponentially. The following form of Friedlander's equation has been proposed, and is widely used to describe this rate of decrease in pressure values:

$$P_s(t) = P_{so}\left(1 - \frac{t}{t_o}\right)e^{-b\frac{t}{t_o}}$$

where, Pso is the peak overpressure,

to is the positive phase duration,

b is a decay coefficient of the waveform and

t is the time elapsed, measured from the instant of blast arrival.

2.3 Explosion and types of explosion

There are three types of blast loading according to position of charge which are;

1) Unconfined explosions

There are three types of unconfined explosion which are

(a) Free-air bursts: The explosive charge is detonated in the air, the blast waves propagate spherically outwards and impinge directly onto the structure without prior interaction with other obstacles or the ground.

(b) Air bursts: The explosive charge is detonated in the air, the blast waves propagate spherically outwards and impinge onto the structure after having interacted first with the ground; a Mach wave front is created.

(c) Surface bursts: The explosive charge is detonated almost at ground surface, the blast waves immediately interact locally with the ground and they next propagate hemispherical outwards and impinge onto the structure.

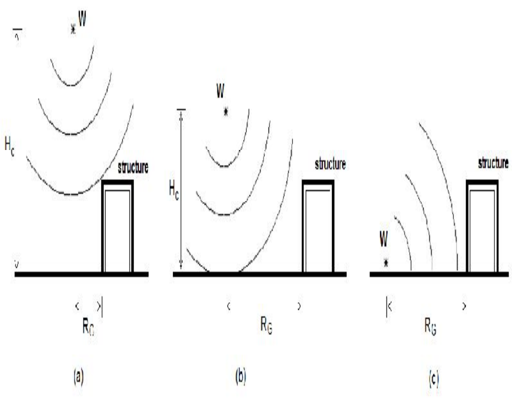


Figure 2: Types of external explosions and blast loadings; (a) Free-air bursts, (b) Air bursts, and (c) Surface bursts.

As shown in figure the height Hc above ground, where the detonation of a charge W occurs, and on the horizontal distance RG between the projection of the explosive to the ground and the structure.

2) confined explosions ;

When an explosion occurs within a building, the pressures associated with the initial shock front will be high and therefore will be amplified by their reflections within the building. This type of explosion is called a confined explosion. In addition and depending on the degree of confinement, the effects of the high temperatures and accumulation of gaseous products produced by the chemical reaction involved in the explosion will cause additional pressures and increase the load duration within the structure. Depending on the extent of venting, various types of confined explosions are possible.

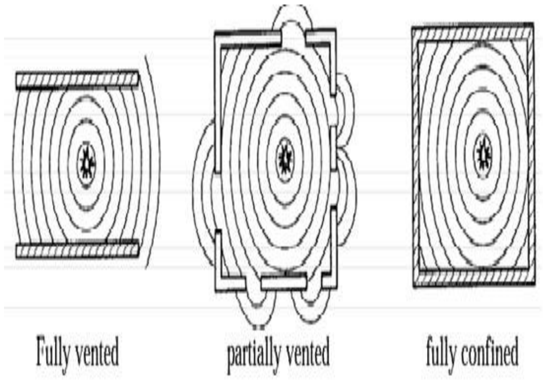


Fig.4 Fully vented, Partially Vented and Fully Confined

3) Explosions caused by explosives attached to the structure;

If detonating explosive is in contact with a structural component, e.g. a column, the arrival of the detonation wave at the surface of the explosive will generate intense stress waves in the material and resulting crushing of the material. Except that an explosive in contact with a structure produces similar effects to those of unconfined or confined explosions.

Shock Waves or Blast Waves

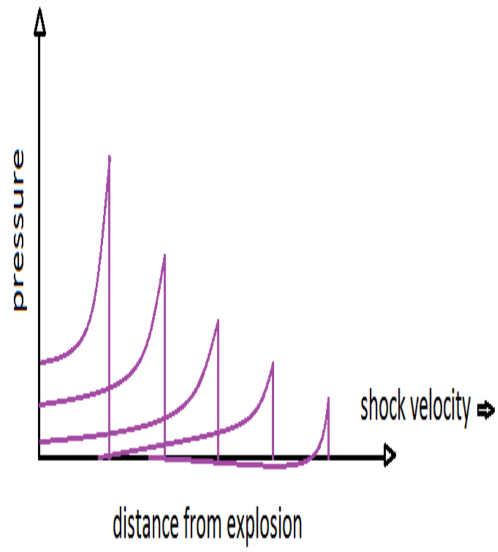


Figure 3 Blast wave propagation

From the figure 3 it can be concluded that if the explosive source is spherical, the resulting shock wave will be spherical, since its surface is continually increasing, the energy per unit area continually decreases.

Consequently, as the shock wave travels outward from the charge, the pressure in the front of the wave, steadily decreases. At great distances from the charge, the peak pressure is infinitesimal, and the wave can be treated as a sound wave. Behind the shock wave front, the pressure in the wave decreases from its initial peak value.

Blast wave reflection:

When the blast wave comes to contact with a rigid surface the pressure that is reflected is larger than the incident peak pressure Pso shown at Figure 3.1 The reason for this rise is attributed to the nature of the propagation of the blast wave through the air. While the wave travels, it moves along air particles that collide with the surface upon arrival. In an ideal linear-elastic case the particles should be able to bounce back freely leading to a reflected pressure equal to the incident pressure, and thus the surface would experience a doubling of the acting pressure. In a strong blast wave, which as a shock wave is a non-linear phenomenon, the reflection of these particles is obstructed by subsequent air particles that are transferred there, thus leading to much higher reflected pressure values. In this case the surface would experience an acting pressure much higher than the incident one.

Three types of reflection can take place depending on the angle of the reflecting surface with the propagation direction of the blast wave.

1) when a surface is perpendicular to the direction of the wave, during which normal reflection occurs.

2) When the propagation direction of the wave intersects at a small oblique angle with the surface it causes the creation of an oblique reflection.

3) Third case is linked to a phenomenon known as Mach stem creation, which occurs whenever the wave impinges on a surface at a specific angle.

IV. ANALITICAL INVESTIGATION

4.1 Time History Analysis

Time-history analysis is used to determine the dynamic response of a structure to arbitrary loading. The dynamic equilibrium equations to be solved are given by,

$$Ku(t) + C\dot{u}(t) + M\ddot{u}(t) = r(t)$$

where, K is the stiffness matrix, C is the proportional damping matrix, M is the diagonal mass matrix, u, $\dot{u}$and $\ddot{u}$ are the relative displacements, velocities, and acceleration with respect to the ground, and r is the applied load. If the load includes ground acceleration, the displacements, velocities, and accelerations are relative to this ground motion

Any number of time- history load Cases can be defined. Each time-history case can differ in the load applied and in the type of analysis to be performed. There are several options that determine the type of time-history analysis to be performed: 1) Linear vs. Nonlinear 2) Modal vs. Direct-integration: These are two different solution methods, each with advantages and disadvantages. Under ideal circumstances, both methods should yield the same results to a given problem. 3) Transient vs. Periodic: Transient analysis considers the applied load as a one-time event, with a beginning and end. Periodic analysis considers the load to repeat indefinitely, with all transient response damped out. Periodic analysis is only available for linear modal time-history analysisFor most real structures which contain stiff elements, a very small time step is required to obtain a stable solution. Reducing the integration time step will increase the accuracy, and generally a time step size which is less than 0.01 times the dominating period is selected.

To get consistent results for the 3D building models, the time step had to be reduced to 0.001s. The non-linear direct integration time history analyses are run for a duration of 2 s with 2000 time steps for all the buildings, and encompassed one cycle of structural response.

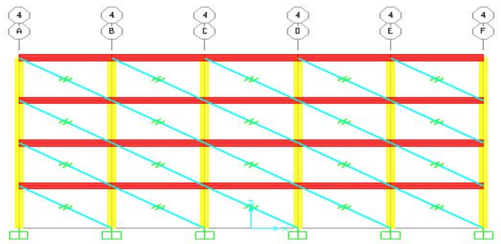
Problem Statement

1) Type of Building RCC Framed Structure
2) Number of storey 3 storey
3) Plan size 20 m X 15 m
4) Floor to floor height: 3 m.
5) Internal walls 230 mm thick
6) Materials Reinforced concrete for the columns and beams
Concrete M30, Rebar Steel Fe-415
7) Loads:
a) Dead loads
i) Slab: 25 D kN/m2
D is depth of slab in meter.
ii) Floor finish 1.0 kN/m2
b) Live load 2 kN/m2
8) Slab thickness 125 mm
9) Elastic modulus of concrete 27386.12 KN/m2
10) Size of beams 600 mm X 600 mm
11) Size of columns 600 mm X 600 mm
12) Density of concrete 25 kN/m3
13) Density of brick masonry 20 kN/m3

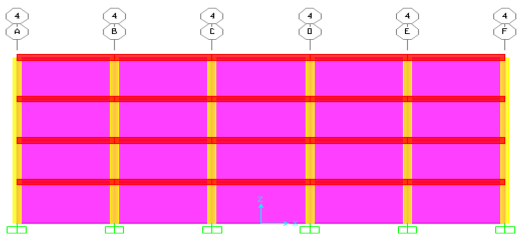
Following models are prepaired for blast analysis load

MODEL NO.1	G+4 bare RCC frame
MODEL NO.2	G+4 bare RCC frame with single dampers
MODEL NO.3	G+4 bare RCC frame with infill walls

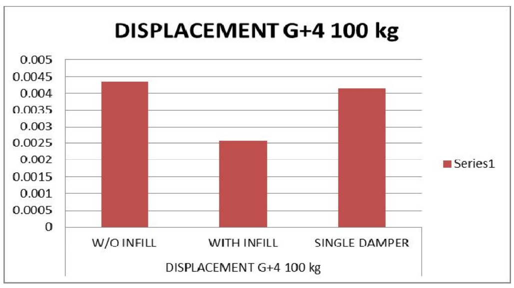
V. RESULT AND DISCUSSION



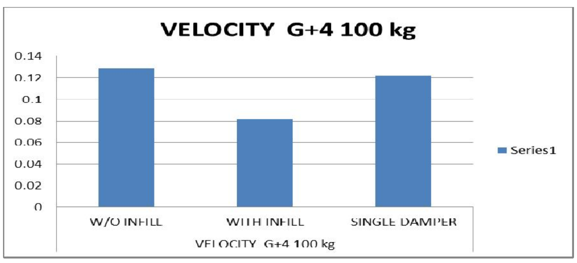
FigNo.5.1G+4 bare RCC frame with single dampers



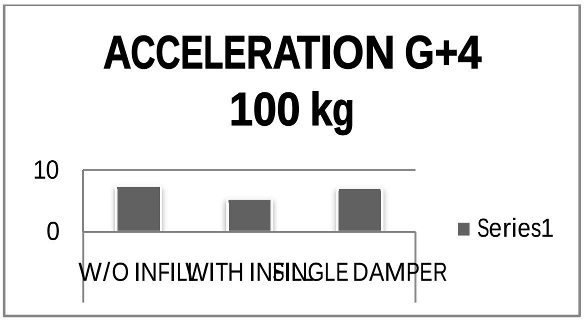
FigNo.5.2 G+4 bare RCC frame with infill walls



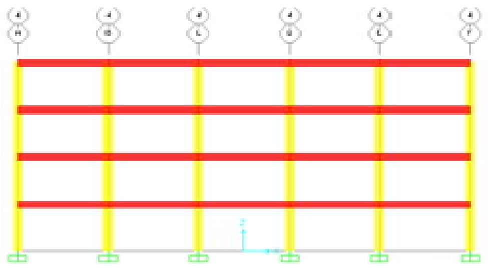
Graph5.1: Displacement G+4 100Kg



Graph.5.2: Velocity G+4 100Kg



Graph.5.3: Acceleration G+4 100Kg



FigNo.5.3 G+4 bare RCC frame

VI. CONCLUSION

Time history analysis is carried out by considering non-linearity and response up to 1second are drawn. After analyzing the plot results appeared for the top joint of frame

From time history analysis building subjected to blast load, following conclusions are drawn,

From non-linear dynamic analysis of building subjected to blast load without and with infill (soft storey), following conclusions are drawn.

1. Masonry infills have significant effect on blast performance of buildings.
2. For G+4 100 kg TNT, due to infill there is 40.82%, 36.10% & 27.83% reduction in displacement, velocity and acceleration respectively.
3. For G+4 200 kg TNT, due to infill there is 44.96%, 32.87% & 23.03% reduction in displacement, velocity and acceleration respectively.
4. For G+4 300 kg TNT, due to infill there is 44.44%, 31.6% & 21.558% reduction in displacement, velocity and acceleration respectively.
5. For G+4 400 kg TNT, due to infill there is 44.186%, 31.24% & 21.51% reduction in displacement, velocity and acceleration respectively.
6. Plastic hinges are formed in all models and are found below collapse level.
7. In soft storey building plastic hinge are formed at ground floor and first floor. But in bare frame plastic hinges are formed in almost all floors. It shows walls have higher resistance to blast load and it also define weak storey of building. .
8. Blast can create significant effect on building. so, it's necessary to design important structure for blast load.

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