A Major Project Thesis

“Analysis of TNT induced Surface Blast Loading on Regular G+4 RCC framed building”

Submitted in partial fulfillment of the requirements

for award of the Degree of

MASTER OF TECHNOLOGY IN STRUCTURAL ENGINEERING

Submitted By

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Declaration

I hereby declare that this written submission represents my ideas in my own words and where others ideas or words have been included. I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresentated or fabricated or falsified any idea/data/fact/source in my submission.

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Date: ………………….

Certificate

This is to certify that the project entitled **“Analysis of TNT induced Surface Blast Loading on Regular G+4 RCC framed building”**is a record of bona-fide dissertation work carried out by me, AbhinavNayyar, student of Master of Technology in Civil (Structure) Engineering from Delhi technological university, Delhi 2014-2016 towards the partial fulfillment of the requirements of the award of degree of Master of Technology in Structural Engineering.

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Abstract

Since past few decades there had been an increased emphasis on designing a structure for blast loading. This is due to increased terrorist activities throughout the world. While the standard structures in most of the countries are designed for the seismic loading, so as to mitigate to a certain extent the catastrophic damage caused by nature, anthropogenic blast loading is proving to be far more catastrophic due to lack of proper techniques and measures to counter its ill-effects.

However there had been continuous efforts by the researchers to predict, analyze and mitigate blast loading and its effects.As a result the building codes of various countries have included provisions for the design and construction of blast resistant buildings. Also the works of various researchers claim that by default, the structures designed to resist the seismic loads perform better in resisting blast loading as well.

In this study an attempt has been made to analyze blast loading on a regular RCC framed structure already designed for the seismic loading (in accordance with the relevant Indian codes), and to study the difference in various building parameters related to response of building.

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1.1 INTRODUCTION

The development of human race has seen tremendous evolution in science and technology that has not only raised the standard of life and assured comfortable and civilized life, but have also seen development of mass destruction instruments that can take lives of millions of people in a single go. With the advent of time there had been development of different chemicals which burn abruptly thereby releasing considerable amount of energy which proves to be catastrophic both for life and property. The phenomenon of this abrupt release of energy accompanied with burning of a chemical compound is known as “BLAST”.

There had been a number of terrorist attacks throughout the world in the recent past and some of them have been so catastrophic that they have resulted in a number of initiatives to study the resistance of the structures to blast. Additionally a number of research projects have been undertaken or are underway with an aim to develop mechanisms and systems that can help reduce the hazard of such attacks in any part of the world, thereby aiming to protect the lives of inhabitants, the rescue workers and the nearby people who could be killed or injured badly due to collapse or falling of the debris of the structure subjected to blast.

From point of view of structural engineering and construction, a building can be definitely designed to withstand a terrorist bomb attack with minimal or no damage however practically it might not be possible keeping aesthetics of building in view. Also building designed to with stand blast needs a significantly higher amount of funding and resources and even internal functionality of building may suffer. Although in case of military installations, the high cost and bunker like appearance of a building can be justified, however, for civilian buildings, such high costs cannot be afforded and the loss of aesthetics may not always be acceptable(……………………………………………).

Several studies carried out in past indicate that the RCC structures designed for sustaining seismic loads also perform well under blast loading. This could be attributed to the fact that both seismic and blast loading is dynamic in nature though blast loading is applied 1000 times faster. Despite of structure being designed to resist seismic forces, the analysis of structure should be done separately for blast loading owing to the difference in the manner in which the structure is loaded in both the cases. While in case of earthquake, whole of the structure is loaded simultaneously owing to ground shaking, in case of blast loading only particular face of the structure is loaded most severely as compared to other parts of the structure.

Existing relevant Indian codes do contain procedure to carry out seismic and blast analysis but the blast related code is not as elaborate as the seismic codes and thus an attempt has been made in this study to assimilate the codal provisions mentioned and the external references and literature so as to study the additional requirements of a building to be resistant to blast loads.

1.2 BACKGROUND

The previous few decades have witnessed an increase in the number and magnitude of terrorist blasts. The potential terror targets have also changed from important public buildings in the past to residential buildings with an aim to carry out maximum destruction. Series of blast in Mumbai on 12th march 1993, Brussels attack on 22nd march 2016 and many other blasts that have occurred in past, indicate the vulnerability of public and residential buildings to the blast loading. These buildings range from simple framed reinforced concrete structures to steel structures and even masonry buildings In Indian perspective. Thus study of behavior of moment resisting frames both in steel and reinforced cement concrete under blast loading has become an area of interest.

With the development in the field of engineering and design and most importantly introduction of computers as an aid, there had been a predominant shift in the design philosophies. In the past, structures were generally overdesigned to withstand even the normal load conditions and thus they were usually capable of tolerating some abnormal loads like blast loading. Modern building design and construction practices has enabled one to build lighter and more optimized structural systems with considerably lower over design characteristics. Thus blast load analysis becomes all the more important.

Structural detailing plays a very significant role during a building’s response to blast in the same way as it affects the response of the building to earthquake. This could be attributed to the fact that most of the design codes throughout world, lay an emphasis on increasing the ductility of the structural elements so as to make them withstand higher dynamic stresses thereby permitting the deformation of material well within the plastic stage as well. So besides analysis of structure under blast loading, proper ductile detailing of the structure as per available codes also becomes important.

1.3 OBJECT AND SCOPE

Within the scope of this study, it is intended to:

1. To develop knowledge of explosive materials, blast phenomenon and its effects on regular building type structures based on literature.

2. To carry out design of a regular framed RCC building in seismic Zone V using computer software Etabs.

3. To carry out the analysis of same building under blast loading using computer software SAP 2000 and study the differences.

1.4 DEFINITIONS AND TERMINOLOGY

It is necessary to discuss essential definitions and terminology related with explosives and blast for developing a comprehensive understanding of the same. Basic source of information for these definitions and concepts is World Wide Web and Indian code IS: 4991-1968.

Some of the blast related terminologies can be defined as:-

Explosion: The phenomenon involving release of energy that causes a pressure discontinuity or blast wave is known as explosion.

High-order explosions: Explosions that result in release a lot of heat and high magnitude of shock waves wherein about 50% of the energy in a blast goes to heat and the remaining 50% goes to shock waves.

Detonation: Release of energy caused by the extremely rapid chemical reaction of a substance in which the reaction front advances into the un-reacted substance at equal to or greater than sonic velocity. Detonation is an exothermic reaction characterized by the presence of a shock wave in the material that establishes and maintains the reaction. A distinctive characteristic of detonation is that the reaction zone propagates at a speed greater than the speed of sound.

Detonator: Used to trigger bombs, shape charges and other forms of explosive device. Detonators are often attached to a timer to ensure that the explosion takes place at the desired time, or when the person laying the explosives has reached a safe distance from the blast. Detonators can be chemical, mechanical, or a combination.

Deflagration: Chemical reaction of a substance in which the reaction front advances into the un-reacted substance at less than sonic velocity. Where a blast wave is produced that has the potential to cause damage, the term explosive deflagration may be used.

Ballistic Impact: Ballistic Impact refers to initiating a unit of ammunition or other energetic material by an impact of a ballistic threat as a bullet or other high velocity projectile.

Overpressure (or peak pressure): It is the rise in pressure above atmospheric pressure due to the shock wave from a blast. It generally appears approx. 1/10th to 5 milliseconds after detonation, depending on scaled distance. Safety standards for buildings and inhabited areas are typically based on maximum peak pressures.

Impulse: Impulse is the momentum (mass x velocity) imparted in a blast and is determined by the area under the pressure-time curve.

Quasi-Static Pressure: Quasi-static pressure is a major effect in a confined blast. In a room or large space gas pressure will build up to a fairly constant level; however, in a confined space gas pressure just builds until either the walls blow out (vent) or the confined hot gas cools down. The pressure determines required hoop strength in containers and buildings.

Reflected Overpressure: It is the overpressure formed due to reflection of a shock wave upon striking a surface. If the shock front is parallel to the surface, the reflection is normal.

Blast wind: It is the moving air mass along with the over-pressures resulting from pressure difference behind the shock wave front. The blast wind movement during the positive phase of the overpressure is in the direction of shock front propagation.

Clearance Time: This is the time in which the reflected pressure decays down to the sum of the side on overpressure and the drag pressure.

Decay Parameter: It is the coefficient of the negative power of exponent e governing the fall of pressure with time in the pressure-time curves.

Drag Force: It is the force on a structure or structural element due to the blast wind. On any structural element, the drag force equals dynamic pressure multiplied by the drag coefficient of the element.

Ductility Ratio: It is the ratio of the maximum deflection to the deflection corresponding to the elastic limit.

Dynamic Pressure: It is the pressure effect of air mass movement called the blast wind.

Equivalent Bare Charge: It is the weight of a bare high explosive charge geometrically similar to any given cased charge, which produces the same blast field as the given cased charge.

Ground Zero: It is the point on the earth surface vertically below the explosion.

Shock Wave Front: It is the discontinuity between the blast wave and the surrounding atmosphere. It propagates away from the point of explosion in all directions at a speed greater than the speed ofsound in the undisturbed atmosphere.

Side-on Overpressure: It is the overpressure if it is not reflected by any surface.

Transit Time: It is the time required for the shock front to travel across the structure or its element under consideration.

Yield: It is a measure of the size of the explosion expressed in equivalent weight of reference explosive.

Scaled Distance: Scaled distance is the main way of comparing different blasts. The definition is:

$$\text{Scaled distance} = \frac{\text{Actual distance of point under consideration}}{W\text{^}(1/3)}$$

Where W=   Yield of explosion in equivalent weight of the referenceexplosive measured in tonnes,

Besides definitions and terminologies, study of different types of explosives is also imperative to develop a sound understanding of blast loading. Some of the explosives are:-

Ammonium Nitrate / Fuel Oil (ANFO): It is a crude but effective explosive readily available in markets owing to its use as a fertilizer in agricultural sector and mining industry. In mining industry it is used to break rocks and expose ore.
Ammonium nitrate is a product of chemical reaction between ammonia and nitric acid in aqueous media. The reaction is a highly exothermic reaction that results in evaporation of water thereby leaving behind a concentrated ammonium nitrate melt. The hot melt is then processed into granules and coated with a conditioning agent such as clay to prevent it from caking.

Ammonium nitrate fertilizer is an oxidizing agent and it readily oxidizes organic matter. Besides being widely used as a fertilizer in the agricultural sector, it is also used as principal base material in slurry explosives and low cost blasting agents. To increase its effectiveness as an explosive, it is usually mixed with carbonaceous fuels. Although chemically the same as the fertilizer grade, the ammonium nitrate used for blasting purposes is of a lower density, usually less than 0.85 grams per cubic centimeter and containing small percentages of anti-caking agents.

Ammonium nitrate has roughly 50 percent of the strength of TNT when detonated completely. It yields an energy release of approximately 400 calories per gram. TNT when detonated yields an energy release of approximately 750 to 900 calories per gram.
More than two million pounds of these mixtures, commonly referred to as ANFO (Ammonium Nitrate Fuel Oil), are consumed each year. They account for approximately 80% of the domestic commercial market. ANFO products have found extensive use in a variety of blasting applications including surface mining of coal, metal mining, quarrying and construction. Their popularity has increased because of economy and convenience. The most widely used ANFO product is oxygen balanced free-flowing mixture of about 94% ammonium nitrate granules and 6% Diesel fuel oil.

C-4: It is a very common variety of military plastic explosive and is made up of explosive, binder, plasticizer and marker or taggant chemicals. As in many plastic explosives the explosive material in C-4 is RDX (Cyclonite, cyclo tri-methylene tri-nitramine) which makes up around 90% of the C-4 by weight. The binder is poly-isobutylene (5.5%) and the plasticizer is di (2-ethylhexyl) or dioctylsebacate (2%). In the U.S., the marker is DMDNB (2, 3-dimethyl-2, 3-dinitrobutane). Another binder used is dioctyladipate (DOA). A small amount of petroleum oil is also added.

Dynamite: Dynamite was invented by Alfred Nobel in 1867 and is widely used for mining, demolitions and other purposes. It does not explodes easily and hence risk of accidental explosion is minimum which makes it a safer alternative to gunpowder and other explosive used earlier.

Trinitrotoluene (TNT): It is a pale yellow crystalline hydrocarbon, an aromatic compound that melts at 81 °C. TNT itself is an explosive chemical however it is mostly used with some other explosive as a mixture. Ammonium nitrate and TNT are mixed together to make an explosive “Amatol”.

Nitroglycerin: It is obtained by nitrating glycerol and is a heavy colorless poisonous oily explosive liquid. It is used in the manufacture of explosives, specifically dynamite, and as such is employed in the construction and demolition industries.

RDX: RDX is an explosive nitro amine (cyclo-trimethylene-trinitramine) and is widely used in military and industrial applications.
In its pure, synthesized state RDX is a white, crystalline solid. As an explosive it is usually used in mixtures with other explosives and plasticizers or desensitizers. It is stable in storage and is considered one of the most powerful and brisant of the military high explosives. RDX is also used as a major component of many plastic bonded explosives used in weapons.

Semtex: It is a general purpose plastic explosive, used in commercial blasting, demolition, and in certain military applications. Being difficult to detect by even modern explosive detector machines employed at places of high security, it has become very popular with terrorist groups. Semtex was used as an explosive in Pan Am Flight 103 attack.

Plastic Explosive: It is a specialized form of explosive material which is soft, hand malleable and may have the added benefit of being usable over a wider temperature range than the pure explosive. Plastic explosives are especially suited for explosive demolition as they can be easily formed into the best shapes for cutting structural members, and have a high enough velocity of detonation and density for metal cutting work. They are generally not used for ordinary blasting as they tend to be significantly more expensive than other materials that perform just as well in that field. Also, when an explosive is bound in a plastic, its power is generally lower than when it is pure.

CHAPTER 2

EXPLOSION/ BLAST, BLAST LOADING CATEGORIES, BLAST LOAD CHARACTERISTICS, BLAST STRUCTURE INTERACTION

2.1 EXPLOSIONS AND BLAST PHENOMENON

Blast loading analysis on a structure has gained importance since last few decades and works of T.Ngo, P.Mendis, A.Gupta and J.Ramsay of university of Melbourne is considered to be a pioneer one as far as blast loading and its effects on structures is concerned. There are multiple definitions of an “explosion” as cited in works of different researchers but all these definitions conclude blast as a large scale, rapid and sudden release of energy as has been described by Mendis, Gupta and Ramsay in their works.

Depending upon the nature of explosion and particularly on the method of abrupt release of this large scale energy, explosions can be divided into three major types as:-

1) Physical explosion
2) Nuclear explosion
3) Chemical explosion

Physical explosions are the ones that involve only physical processes. These explosions typically include large scale of energy release from the catastrophic failure of a cylinder of compressed gas, volcanic eruptions or even mixing of two liquids at different temperatures. Thus physical explosions may be natural or anthropogenic in nature.

In a nuclear explosion, energy is released from the formation of different atomic nuclei by the redistribution of the protons and neutrons within the interacting nuclei. The process involved in nuclear explosion may either be a fission or fusion process depending upon the type of explosive involved. The atomic bomb that was used by the United States on Japan in the year ……. Is one of the sole example of nuclear explosion as witnessed by the world. No designer could claim to design an above ground building resistant to nuclear explosion and hence it is unworthy to study the effect of nuclear explosions on buildings.

In chemical explosion, rapid oxidation of fuel elements (hydrocarbons) result in an abrupt release of energy in short time duration and the process of the same is known as chemical explosion (Smith and Hetherington, 1994).

Apart from classification of explosives based on their nature, they can also be classified according to their physical state as solids, liquids and gases.

Solid explosives are mainly high explosives for which blast effects are best known. They can also be classified on the basis of their sensitivity to ignition as secondary or primary explosive. (Mendis, Gupta, Ramsay, 2007) The latter is one that can be easily detonated by simple ignition from a spark, flame or impact. Secondary explosives when detonated create blast (shock) waves which can result in widespread damage to the surroundings. Examples include trinitro-toluene (TNT) and Ammonium Nitrate/Fuel Oil (ANFO).

Sometimes explosions are classified as thermal explosions and non-thermal explosions. (Longinow, 2003) A thermal explosion is one which burns suddenly (detonates) resulting in a violent expansion of gases with great disturbing force and a loud noise. (Smith, Hetherington) The detonation of an explosive device made up of ammonium nitrate/fuel oil (ANFO), such as the explosions in Istanbul in 2004, is widely known as an example of a thermal explosion. A non-thermal explosion describes a sudden bursting because of buildup of pressure within a container. An example is the filling of a tank with air under pressure, and the tank suddenly bursts producing an explosion. (Longinow, 2003)

Longinow further defines an explosive as a “device that involves the use of a solid or liquid that explodes if ignited, shocked, or subjected to heat or friction”. Examples are nitroglycerine, ammonium nitrate/fuel oil mixtures, TNT, dynamite, lead azide, RDX, gunpowder, and dynamite.

Debate is ongoing in the issue whether something will explode or not and it requires investigation on a case-by-case basis. Some materials such as copper azide will detonate at the slightest shock or movement whereas others such as TNT or RDX may require another explosive (called a primary explosive, or a blasting cap) to detonate the material (PEAK Inc., www.peak.com.). Therefore, there is no easy way of predicting whether a particular material is explosive; a case-by-case investigation is required. However if an oxidizing material (e.g. ammonium perchlorate, potassium permanganate, ammonium nitrate, etc.) can be placed in intimate contact with a fuel source this is a basic recipe for an explosive material. Longinow states that “if the oxidizing part can be incorporated into the molecule itself (e.g. nitric acid plus glycerin to yield nitroglycerine), a powerful explosive is produced. A very well known example is trinitrotoluene, also called 2, 4, 6-trinitrotoluene, or “TNT” for short, which is manufactured from toluene (toluene is the fuel part of the molecule;three “nitro-” groups are the oxidizing part).” If certain combustible metal powders such as aluminum can also be mixed in with the material, the explosive capability may be enhanced. Many explosive chemicals have nitrogen in the form of nitrate (a nitrogen atom linked to three oxygen atoms) or nitro- (a nitrogen atom linked to two oxygen atoms) or azide (two nitrogen atoms linked together) incorporated as part of the organic molecule (Smith and Hetherington, 1994).
Dynamite is a detonating explosive containing a liquid explosive ingredient(usually nitroglycerine or a similar organic nitrate ester or both) that is uniformly mixed with an adsorbent material such as wood pulp and usually contains materials such as nitrocellulose, sodium and/or ammonium nitrate (TM 5-1300, 1990). All of these fall into the general category of thermal explosions.

As per Mendis et al, “Explosion in general results from detonation of a condensed high explosive generating hot gases under a pressure of up to 300 kilo bar and a temperature of about 3000-

4000C°. The hot gas expands forcing out the volume it occupies. As a consequence, a layer of compressed air (blast wave) forms in front of this gas volume containing most of the energy released by the explosion."

Explosion is accompanied by a blast wave which results in an instantaneous increase in pressure above ambient atmospheric pressure. Also the speed of blast wave sometimes exceeds the speed of sound. As per blast literature, this instantaneously increased pressure due to blast wave is known as peak overpressure. Peak overpressure is an indicator of the intensity of blast however it decreases as the shock wave expands outward from the explosion source.

After a short time, the pressure behind the front may drop below the ambient pressure as seen in figure 2.1 below in which after time t5 the pressure drops below ambient pressure.

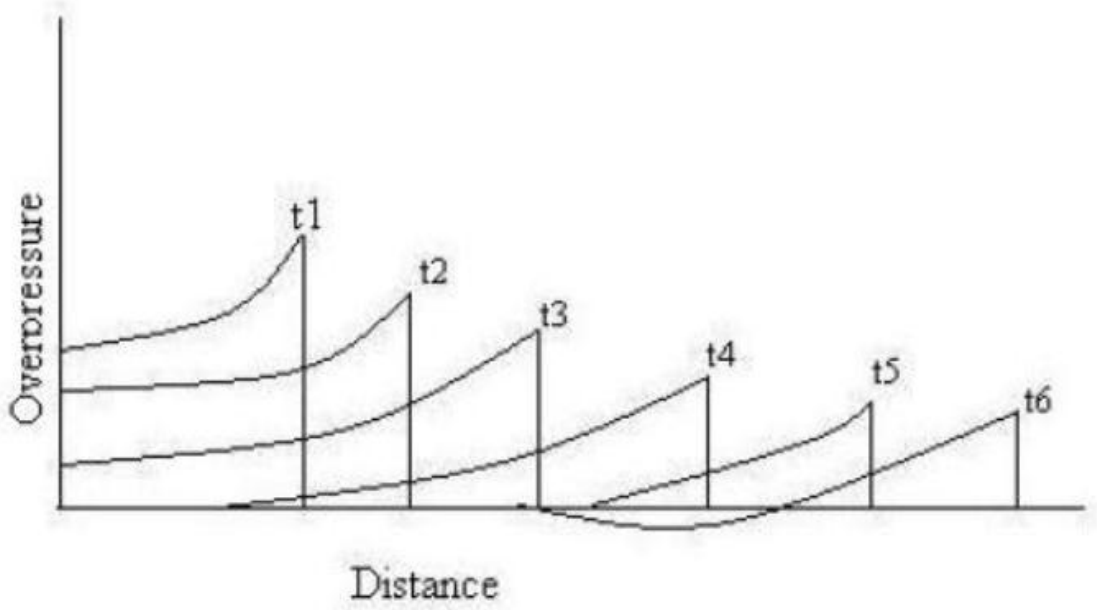


Fig 2.1 Variation of overpressure with distance and time

The duration for which the pressure decreases from peak value to zero is known as positive phase and duration for which the pressure is negative or below ambient atmospheric pressure is termed as a negative phase. While a positive thrust is generated during positive phase of blast, a partial vacuum is created and air is sucked in during negative phase. Negative phase is also accompanied by high suction winds that carry the debris for long distances away from the explosion source (Mendis, Gupta, and Ramsay, 2007).

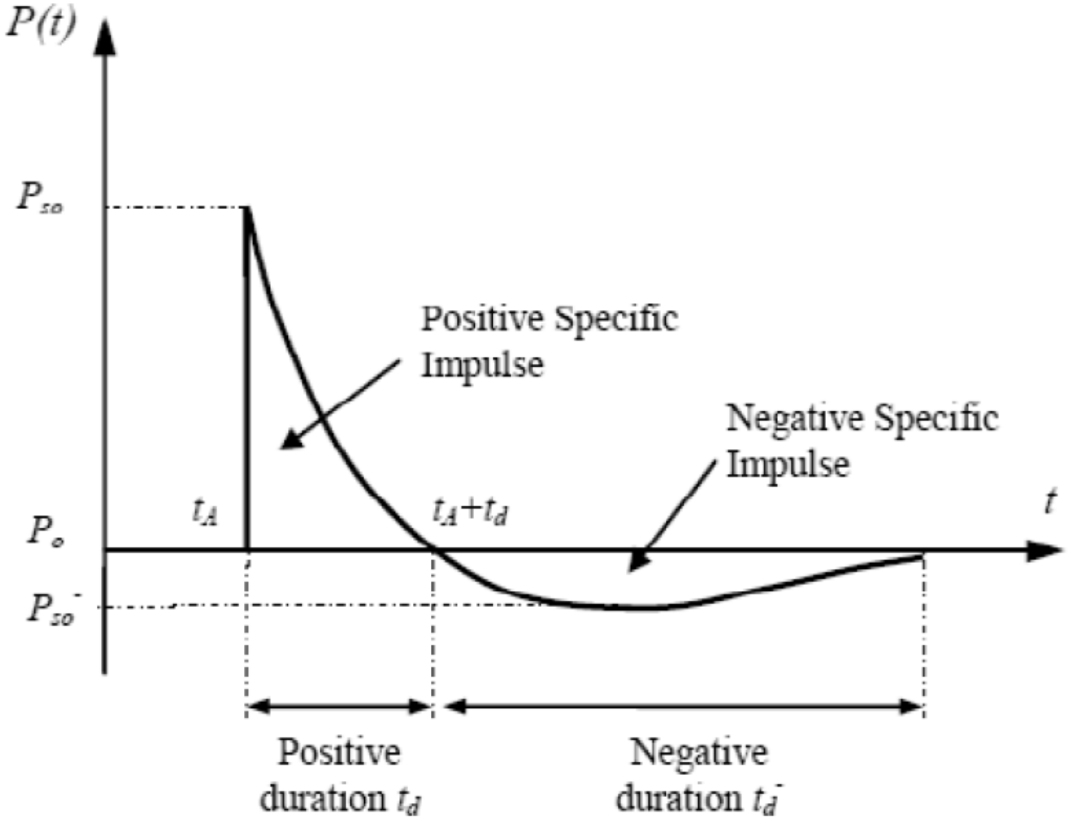


Fig 2.2 Variation of blast pressure with time

Mendis, Gupta & Ramsay defines basic properties of a material calledexplosive material as:

1. An explosive "must contain a substance or mixture of substances that remains unchanged under ordinary conditions, but undergoes a fast chemical change upon stimulation."

2. Explosion resulting reaction "must yield gases whose volume under normalpressure, but at the high temperature resulting from an explosion is much greater than that of the original substance."

3. The change must be exothermic in order to heat the products of the reaction and thus to increase their pressure."

Some other concepts based on the book by Smith and Hetherington (1994) are as follows:

Chemical Explosive: A compound or mixture which, upon the application of heat or shock, decomposes or rearranges with extreme rapidity, yielding much gas and heat.Many substances not ordinarily classed as explosives may do one, or even two, of these things. For example, a mixture of nitrogen and oxygen can be made to react with great rapidity and yield the gaseous product nitric oxide; yet the mixture is not an explosive since it does not evolve heat, but rather absorbs heat.

For a chemical to be an explosive, it must exhibit all of the following:

1) **Formation of Gases:** Gases may be evolved from the chemical substance in a variety of ways. One such way is wood or coal is pulverization. In the process of pulverization of wood or coal, burning in furnace in the presence of air results in formation of a number of gasses. When the wood or coal is immersed in liquid oxygen or suspended in air in the formof dust, the burning takes place with explosive violence. In each case, the sameaction occurs: a burning combustible forms a gas.

2) **Evolution of Heat:** Every chemical explosion is accompanied by generation of heat in large quantities. The heat is liberated rapidly and causes the gaseous products of reaction to expand and generate high pressures. This rapidgeneration of high pressures of the released gas constitutes the explosion. Insufficient rapidity in the generation of high gas pressures will not cause anexplosion.

3) **Rapidity of Reaction:** Rapidity of reaction distinguishes the explosive reactionfrom an ordinary combustion reaction. Unless the reaction occurs rapidly, the thermally expanded gases will be dissipated inthe medium, and there will be no explosion. Again, consider a wood or coal fire. Asthe fire burns, there is the evolution of heat and the formation of gases, but neither isliberated rapidly enough to cause an explosion.

4) **Initiation of Reaction:** A reaction must be capable of being initiated by theapplication of shock or heat to a small portion of the mass of the explosive material.A material in which the first three factors exist cannot be accepted as an explosiveunless the reaction can be made to occur when desired.

2.2 EXPLOSIVE AIR BLAST LOADING

The threat for a conventional bomb is defined by two equally important elements, the bomb size or charge weight W and the standoff distance R betweenthe blast source and the target. For explosions where bomb size is high and standoff distance is less, catastrophic and large scale damages are caused. For example,the blast occurred at the basement of World Trade Centre in 1993 had the chargeweight of 816.5 kg TNT and it led to collapse of the world’s tallest standing building at that time though melting of steel in the stories where the aircraft collided was also attributed to be cause of such high catastrophic damage. The Oklahoma bomb in 1995 had a charge weight of 1814 kg at a stand-off of 4.5m and is a subtle example of high order of damages incurred to both life and property.

As terrorist attacks may range from the small letter bomb tothe gigantic truck bomb as experienced in Oklahoma City, the mechanics of aconventional explosion and their effects on a target must be addressed. The observedcharacteristics of air blast waves are found to be affected by the physical propertiesof the explosion source. A typical building subjected to blast loading on one of its face is shown in the figure below.

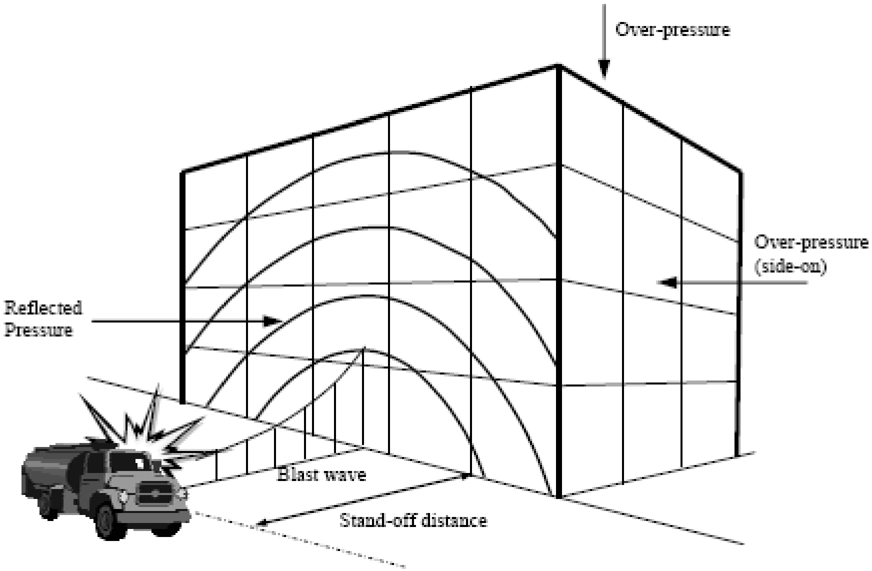


Fig 2.3 Building subjected to blast loading

The variation of blast pressure with time has been shown in the figure below. At the arrivaltime *tA*, following the explosion, pressure at that position suddenly increases to apeak value of overpressure, *Pso*, over the ambient pressure, *Po*. The pressure thendecays to ambient level at time *td*, then decays further to an under pressure *Pso*-(creating a partial vacuum) before eventually returning to ambient conditions at time*td* + *td*-. The quantity *Pso*is usually referred to as the peak side-on overpressure,incident peak overpressure or merely peak overpressure (TM 5-1300, 1990).

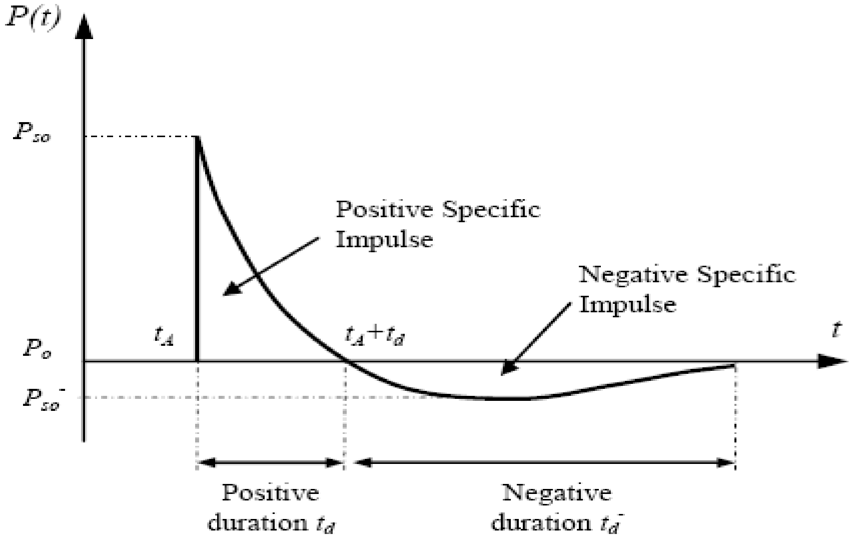


Fig 2.4 Variation of blast pressure with time

Smithand Hetherington (1994) states that, incident peak over pressures *Pso*are amplified bya reflection factor as the shock wave encounters an object or structure in its path.Except for specific focusing of high intensity shock waves at near 45° incidence,these reflection factors are typically greatest for normal incidence (a surface adjacentand perpendicular to the source) and diminish with the angle of obliquity or angularposition relative to the source. “Reflection factors depend on the intensity of theshock wave, and for large explosives at normal incidence these reflection factorsmay enhance the incident pressures by as much as an order of magnitude(Mendis, Gupta, Ramsay and Ngo).”

Throughout the pressure-time profile, two mainphases can be observed; portion above ambient is called positive phase of duration *td*,while that below ambient is called negative phase of duration, *td-*. The negative phaseis of a longer duration and a lower intensity than the positive duration. As the standoffdistance increases, the duration of the positive-phase blast wave increasesresulting in a lower-amplitude, longer-duration shock pulse. Charges positionedextremely close to a target structure impose a highly impulsive, high intensitypressure load over a localized region of the structure; charges positioned furtheraway produce a lower-intensity, longer-duration uniform pressure distribution overthe entire structure. Eventually, the entire structure is surrounded in the shock wave,with reflection and diffraction effects creating focusing and shadow zones in acomplex pattern around the structure. Negative phase is the phase known to cause theweakened structure is subjected to impact by debris that may cause additionaldamage to property and life (Smith and Hetherington, 1994).

If the exterior building walls are capable of resisting the blast load, the shockfront penetrates through window and door openings, subjecting the floors, ceilings,walls, contents, and people to sudden pressures and fragments from shatteredwindows, doors, etc. Building components not capable of resisting the blast wavewill fracture and be further fragmented and moved by the dynamic effect of the blastpressure that immediately follows the shock front. Building contents and people willbe displaced in the direction of blast wave propagation. In this manner the blast willpropagate through the building.

2.3 Blast Wave Scaling Laws

Smith and Hetherington (1994) mention that all blast parameters are primarilydependent on the amount of energy released by a detonation in the form of a blastwave and the distance from the explosion. According to commonly acceptedstandard TM 5-1300,1990, a universal normalized description of the blast effects canbe given by scaling distance relative to $(E/P\text{o})^{1/3}$ and scaling pressure relative to *P*o,where *E* is the energy release (kJ) and *P*o the ambient pressure (typically 1atmosphere or 101.3 kN/m2). For convenience, however, it is general practice toexpress the basic explosive input or charge weight *W* as an equivalent mass of TNT.This is due to the fact that, blast science is first evolved with inventing of TNT.Therefore, blast effects of TNT have been very well studied. All other explosives arecompared to TNT. Even nuclear explosions are rated in terms of TNT equivalents.(Longinow, 2003)

Results are then given as a function of the dimensional distance parameter(scaled distance) $Z = R/W^{1/3}$, where *R* is the actual effective distance from theexplosion. *W* is generally expressed in kilograms. Scaling laws provide parametriccorrelations between a particular explosion and a standard charge of the samesubstance.

2.4 Prediction of Blast Pressure

Blast wave parameters for conventional high explosive materials have beenthe focus of a number of studies during the 1950’s and 1960’s following the WorldWar II by scientists such as Baker and Brode. Based on Mendis et.al.evolution ofsuch equations is summarized as follows. Estimations of peak overpressure due tospherical blast based on scaled distance $Z = R/W^{1/3}$ was introduced by Brode (1955)as:

$$P_{s0} = \frac{6.7}{Z^3} + 1 \text{ bar } (Pso\rangle 10 \text{ bar})$$

$$P_{s0} = \frac{0.975}{Z} + \frac{1.455}{Z^2} + \frac{5.85}{Z^3} - 0.019 \text{ bar } (0.1 \text{ bar}\langle Pso \langle 10 \text{ bar})$$

On 1961 Newmark and Hansen introduced a relationship to calculate themaximum blast overpressure, *Pso*, in bars, for a high explosive charge detonates atthe ground surface as:

$$P_{s0} = 6784\frac{W}{R^3} + 93\left(\frac{W}{R^3}\right)^{\frac{1}{2}}$$

Another expression of the peak overpressure in kPa is introduced by Mills on1987, in which *W* is expressed as the equivalent charge weight in kilo-grams of TNT,and *Z* is the scaled distance:

$$P_{s0} = \frac{1772}{Z^3} + \frac{114}{Z^2} + \frac{108}{Z}$$

As stated by Smith and Hetherington (1994), as the blast wave propagatesthrough the atmosphere, the air behind the shock front is moving outward at lowervelocity. The velocity of the air particles, and hence the wind pressure, depends onthe peak overpressure of the blast wave. This later velocity of the air is associatedwith the dynamic pressure, *q* (*t*). The maximum value, *qs*, is given by TM 5-1300,1990 as:

$$q_s = 5p_{s0}^2 / 2(p_{s0} + 7p_0)$$

If the blast wave encounters an obstacle perpendicular to the direction ofpropagation, reflection increases the overpressure to a maximum reflected pressure*Pr as*:

$$P_r = 2P_{s0}\left\{\frac{7P_0 + 4P_{s0}}{7P_{s0} + P_{so}}\right\}$$

Various equations as has been recommended by various researchers, to calculate the blast pressure has been shown above. However in the scope of present study, equation as mentioned in IS 4991: 1968 has been used.

2.5 Seismic and Blast Effects on Structures

Seismic and blast loads though being of same nature i.e. dynamic in nature, differ from each other on various grounds.

The firstdifference is in the way a given structure is loaded. In the case of an earthquake, thestructure is subject to ground motions that shake the structure from the ground (baseor foundation). However, in the case of an explosion produced by an air or a surface burst, thestructure is loaded by means of a compression wave (shock wave) over some area.
Since a portion of the blast energy is coupled into the ground, the structure is alsosubject to ground motions similar to an earthquake, though much less intense.

The second difference is on the basis of the duration of loading. Forearthquakes, the duration of induced motions (shaking) can range from seconds tominutes. However for blasts, the duration of induced motions range only a few milliseconds. Thus incase of earthquakes, additional loadings are produced by "aftershocks," which are generally lessintense than the initial shaking.

Further, earthquakes shake an entirebuilding, but produce mostly horizontal loads at floor-slab levels, concentrating inthe specially designed, laterally stiffer structural systems. Blast usually does notattack the entire structure uniformly, but produces the most severe loads to thenearest structural elements, both vertical and horizontal, with little regard to theirstiffness. Uplift pressure load on floors is also a specific blast effect.

2.6 MATERIAL BEHAVIOR AT HIGH STRAIN-RATE

Blast loading has a small time period ranging in milliseconds and as a result they produce very high strain rates in the range of $10^2$to $10^4 s^{-1}$.Such a high loadingrate alters the dynamic mechanical properties of the target structure and also the expected damage mechanism of various structural elements.

For reinforced concrete structures subjected to blast effects the strength ofconcrete and steel reinforcing bars can increase significantly due to strain rateeffects. Figure 2.5 shows the approximate ranges of the expected strain rates fordifferent loading conditions. It can be seen that ordinary static strain rate is located in the range: 10^{-6} to $10^{-5} s^{-1}$, while blast pressures normally yield loads associated withstrain rates in the range: 10^2– $10^4 s^{-1}$.

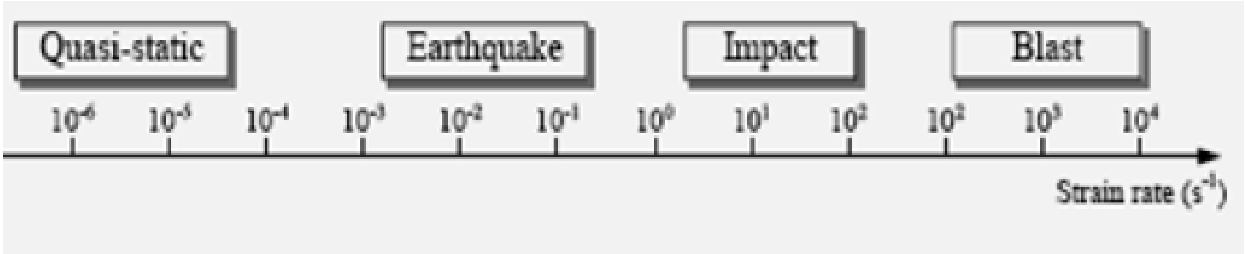


Fig 2.5 Strain rates associated with different types of loading.
(from work of Mendis, Gupta, Ramsay and Ngo, 2007)

2.6.1 Dynamic Properties of Reinforcing Steel under High-Strain Rates

Reinforcing steel is an isotropic material thereby facilitating monitoring and calculation of their elastic and inelastic response to dynamic loading.Norris et al.(1959) tested two steel specimens with different static yield strength of 330 and 278 MPa respectively, undertension at strain rates ranging from $10^{-5}$to 0.1 s^{-1}. Strength increase of 9 - 21% and10 - 23 % were observed for the two steel types, respectively. Harding (1967) conducted tensile experimentsusing the tensile version of Split Hopkinton's Pressure Bar (SHPB) on mild steelusing strain rates varying between $10^{-3}s^{-1}$and 2000 s^{-1}. He concluded that materials having body-centered cubic (BCC) structure (such as mild steel)showed the greatest strain rate sensitivity.
Mendis et.al states, “It has been found thatthe lower yield strength of mild steel can almost be doubled; the ultimate tensilestrength can be increased by about 50%; and the upper yield strength can beconsiderably higher. In contrast, the ultimate tensile strain decreases with increasingstrain rate”.

Indian code IS 4991: 1968 also allows for increase of 25 % in the dynamic strength over static strength of reinforcing steel in RCC structures.

2.6.2 Dynamic Properties of concrete under High-Strain Rates

D.L. Grote et al carried out plate impact and split Hopkinson bar experiments on concrete specimens to generate strain rates over the range of 10^2 to 10^4 s^{-1} andpressures of up to 1.5 GPa. These conditions more closely simulate those found in actualpenetration and explosion.

The dynamic strength of concrete under plate impact was found to be much higher than the corresponding quasi-static strength. Keeping in view the experimental results and observations of various researchers, Indian code IS 4991: 1968 allows for an increase of 25 % in the characteristic compressive strength of concrete to account for an increased dynamic compressive strength.

2.7 STRUCTURAL RESPONSE TO BLAST LOADING

Blast phenomenon is a complex issue as presented so far since; it involvesmuch kind of explosives, interacting with the peripheral conditions. Manyapproaches are developed throughout time to predict expected damage to a structure,some are much analytical and some are more empirical. One of these fast andempirical ways of predicting possible damage to a structure is by means of relatingoverpressure (incident pressure) to the damage level regardless of the distance to thestructure and effect of reflection. By making use of such a method expected damagethat is expected to occur for a given overpressure is predicted as in table 1.

Table 1 Overpressure and expected damage (from work of Longinow,2003)

Overpressure (psi)	**Expected Damage**
0.04	Very loud noise (143 dB); sonic boom glass failures
0.1	Breakage of small windows under strain
0.15	Typical pressure of glass failure
0.3	10% of windows broken
0.5	Windows shattered, limited minor damage to house structures
0.7	Upper limit for reversible effects on humans
1	Partial demolition of houses; corrugated metal panels fail and buckle; skin lacerations from flying glass
2	Partial collapse of walls and roofs of houses
2.4	Eardrum rupture of exposed populations
2.5	Threshold for significant human lethality
3	Steel frame building distorted and pulled away from foundation
5	Wooden utility poles snapped
10	Probable total building collapse. Lungs hemorrhage
20	Total destruction. 99% fatality due to direct blast effects

The Bureau of Alcohol, Tobacco and Firearms (ATF) has published LethalAir Blast Range and Minimum Evacuation Distance values for vehicles carryingexplosives as in a terrorist threat. Table 2 compares these distances with theoverpressure formula listed above, assuming that the explosive is TNT or equivalent.

A possible explosive used by a terrorist is ANFO, prepared by soaking ammonium nitrate prillsin fuel oil (94% ammonium nitrate, 6% fuel oil) and detonated by a highexplosive booster or a blasting cap. ANFO has an explosive power (by weight)approaching that of TNT, or even greater if the ANFO is enhanced with aluminumpowder.

Table 2: Comparison of Formula Calculations with ATF Distances for Vehicles Carrying Explosives. (From work of Longinow, 2003)

Vehicle	Explosive Capacity, lbs	ATF Lethal Air Blast Range, ft.	Equation calc. At P = 3 psi	ATF Minimum Evacuation. Dist, ft.	Equation calc. At P = 0.12 Psi
Compact Sedan	500	100	125	1500	1464
Full Size Sedan	1000	125	157	1750	1840
Cargo Van	4000	200	250	2750	2928
14-ft Box Van	10000	300	339	3750	3974
Fuel Truck	30000	450	489	6500	5753
Semi-Trailer	60000	600	615	7000	7220

Clubbing the information provided in Table 1 and Table 2 above, one can infer that for blast loading having pressure in excess of 3 psi, a lot of damage occurs to the target building. As per table 1, 0.7 psi is the upper range of reversible damages to human. AtP = 2.4 psi, eardrum rupture may occur. P= 2.5 psi to 10 psi and higher is in the range oflethality to humans. As per table 2 the safe evacuating distances have been mentioned for various values of overpressure. However there are differences of opinion in the literature as to what overpressureshould be used for a Protection Action Distance. The 0.12 psi number is suggestedbased on the ATF information.

But as it is obvious from above discussions blast loading structure interactionis not as simple as listed in above tables and accepting above approaches as mainguidance may lead to wrong results. Complexity in analyzing the dynamic response of blast-loaded structures involves the effect of high strain rates, the non-linear inelastic material behavior, the uncertainties of blast load calculations and the time-dependent deformations. Therefore, to simplify the analysis, a number of assumptions related to the response of structures and the loads has been proposed and widely accepted. To establish the principles of this analysis, the structure is idealized as a single degree of freedom (SDOF) system and the link between the positive duration of the blast load and the natural period of vibration of the structure is established. This leads to blast load idealization and simplifies the classification of the blast loading regimes.

2.8 Elastic SDOF Systems

The simplest discretization of transient problems is by means of employing Single Degree of freedom approach. In this approach, whole structure is idealized as an equivalent system of one concentrated mass and one weightlessspring representing the resistance of the structure against deformation. Diagrammatic illustration of the same can be seen in Figure below.

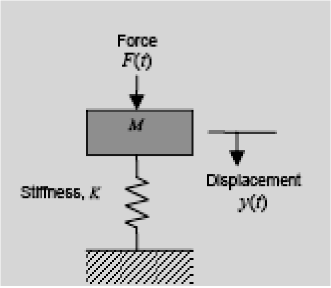


Fig 2.6 SDOF model

In this approach structural mass, *M*, is under theeffect of an external force, *F* (*t*), and the structural resistance, *R*, is expressed in termsof the vertical displacement, *y*, and the spring constant, *K*. The blast load can also beidealized as a triangular pulse having a peak force *Fm*and positive phase duration *td*. The forcing function is given as

$$F(t) = F_m \left(1 - \frac{t}{t_d} \right)$$

The blast impulse is approximated as the area under the force-time curve, andis given by

$$I = \frac{1}{2} F_m t_d$$

The equation of motion of the undamped elastic SDOF system for a timeranging from 0 to the positive phase duration, *td*, is given by Biggs (1964) as

$$M \ddot{y} + Ky = F_m \left(1 - \frac{t}{t_d} \right)$$

The general solution can be expressed as:

Displacement y (t)

$$y(t) = \frac{F_m}{K}(1 - \cos\omega t) + \frac{F_m}{Kt_d}\left(\frac{\sin\omega t}{\omega} - t\right)$$

Velocity v (t)

$$\dot{y}(t) = \frac{dy}{dt} = \frac{F_m}{K}\left[\omega \sin\omega t + \frac{1}{t_d}(\cos\omega t - 1)\right]$$

In which ω is the natural circular frequency of vibration of the structure and *T* is the natural period of vibration of the structure which is given by equation.

$$\omega = \frac{2\pi}{T} = \sqrt{\frac{K}{M}}$$

The maximum response is defined by the maximum dynamic deflection *ym*which occurs at time *tm*. The maximum dynamic deflection *ym*can be evaluated bysetting *dy*/*dt*in Equation 16 equal to zero, i.e. when the structural velocity is zero.

The dynamic load factor, DLF, is defined as the ratio of the maximum dynamicdeflection *ym*to the static deflection *yst*which would have resulted from the staticapplication of the peak load *Fm*, which is shown as follows:

$$DLF = \frac{y_{\max}}{y_{st}} = \frac{y_{\max}}{F_m / K} = \psi(\omega t_d) = \Psi\left(\frac{t_d}{T}\right)$$

The structural response to blast loading is significantly influenced by the ratio*td*/T or ωt_d (*td*/T $=\omega t_d/2\pi$). Three loading regimes are categorized as follows:

$\omega t_d < 0.4$: Impulsive Loading regime.

$\omega t_d > 40$: quasi-static loading regime.

$0.4 < \omega t_d < 40$: dynamic loading regime.

2.9Elasto-Plastic SDOF Systems

Under dynamic blast loading, structural elements are expected to undergo large inelastic deformations so as to absorb some amount of impact energy. Moreover the structural response can be defined by the differential equation ….. as shown earlier. Under such conditions, to obtain an exact solution for the dynamic response of building, non linear dynamic finite element software is required.

However, due to large degree of uncertainty involved in the determination of the loading and interpretation of the resulting deformation, an elasto- plastic single degree of freedom system as proposed by Biggs is commonly used.Interpretation is based on the required ductility factor $\mu = y_m/y_e$

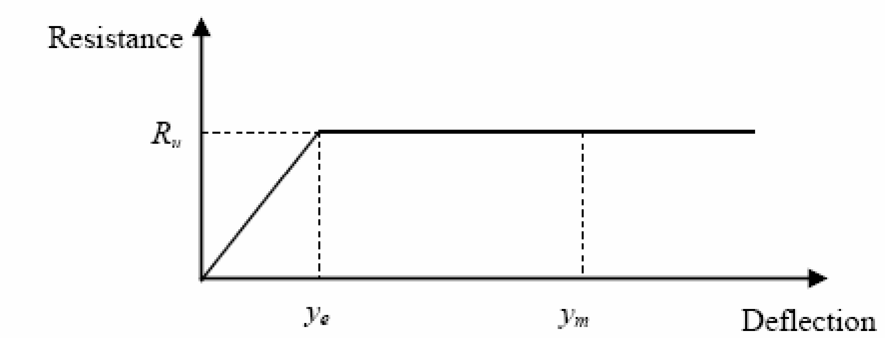


Fig 2.7 Simplified resistance function of an elastoplastic SDOF system
(from work of Mendis, Gupta, Ramsay and Ngo, 2007)

2.10 BLAST WAVE-STRUCTURE INTERACTION

Interaction of a structure with blast wave is a complex phenomenon. Blast loads can excite higher structural modes that are usually neglected for othertypes of hazards. An example of this phenomenon is the vibration of W-sectionflanges (Rittenhouse et. al.). To study the structural behavior under the effect of blast loading, simplification of the overall building geometry is inevitable.Accordingly, in analyzing the dynamic response to blast loading,Hetherington and Smith classify target structures in two types:

1) Diffraction type
2) Drag type

Diffraction type structures are the closedstructures without openings, with the total area opposing the blast. These are subjected to both the shock wave overpressureand thedynamic pressurescaused by blast wind. However drag type structures are the open structures composed of elements like beams, columns, trusses, etc, which have small projected area opposing the shock wave. These are mainly subjected to dynamic pressures by the blast wind.

A building in general will respond to both types of loading(Krauthammer, 2003) and the distinction is made primarily to simplify the analysis.The structural response will depend upon the size, shape and weight of the target,how firmly it is attached to the ground, and also on the existence of openings in eachface of the structure. Above ground or shallow-buried structures can be subjected toground shock resulting from the detonation of explosive charges that are on or closeto ground surface. The energy imparted to the ground by the explosion is the mainsource of ground shock. A part of this energy is directly transmitted through theground as directly-induced ground shock, while part is transmitted through the air asair-induced ground shock. Air-induced ground shock results when the air-blast wavecompresses the ground surface and sends a stress pulse into the ground layers.

Generally, motion due to air-induced ground shock is maximum at the groundsurface and attenuates with depth (TM 5-1300, 1990). The direct shock results fromthe direct transmission of explosive energy through the ground. For a point ofinterest on the ground surface, the net experienced ground shock results from acombination of both the air-induced and direct shocks.

2.11 FAILURE MODES OF BLAST-LOADED STRUCTURES

Unlike seismic loading, the effect of blast loading on a structure is both on a global and local level.The global response relates to the whole building whereas the local response is related to a particular structural element such as a column or a beam. The type of structural response depends mainly on the pressure Vs time loading, the orientation of the target withrespect to the direction of the blast wave propagation and boundary conditions. “Thegeneral failure modes associated with blast loading can be flexure, direct shear orpunching shear. Local responses are characterized by localized breaching andspalling, and generally result from the close-in effects of explosions, while globalresponses are typically manifested as flexural failure.” (Mendiset.al., 2007)

2.11.1 Global Structural Behavior

According to Mendis et.al“ the essential characteristics of loading andbuilding response for transient loads produced by explosions depend primarily on therelationship between the effective duration of the loading and the fundamental periodof the structure on which the loading acts.” The same has been taken into consideration by IS 4991: 1968 and thus as per the Indian standard “When the ratio of time duration t_d to the natural period ofthe element is less than 0.1, the problem may be considered as an impulseproblem taking the area under the pressure ***versus*** time curve as impulseper unit area. In such a case, the shape of pressure-time curve is notimportant”.On the other hand, when theduration of the loading is relatively long compared with the fundamental period, thena quasi-static design can be made.

The global response of structural elements is generally a consequence oftransverse (out-of-plane) loads with long exposure time (quasi-static loading), and isusually associated with global bending (membrane) and shear responses. Therefore,the global response of above ground reinforced concrete structures subjected to blastloading is referred to as membrane/bending failure.

The second global failure modeto be considered is shear failure. It has been found that under theeffect of both static and dynamic loading, four types of shear failure can beidentified: diagonal tension, diagonal compression, punching shear, and direct(dynamic) shear. First three shear response mechanisms have relatively minorstructural effect in case of blast loading since that require high lateral loads similar toearthquake loading and can be neglected. The fourth type of shear failure which isdirect (dynamic) shear failure is primarily associated with transient short durationdynamic loads that result from blast effects, and it depends mainly on the intensity ofthe pressure waves. The high shear stresses may lead to direct global shear failure and itmay occur very early (within a few milliseconds of shock wave arrival to the frontalsurface of the structure) which can be prior to any occurrence of significant bendingdeformations. (Smith and Hetherington, 1994)

2.11.2 Localized Structural Behavior

The close-in effect of explosion may cause localized shear or flexural failurein the closest structural elements. This depends mainly on the distance between thesource of the explosion and the target, and the relative strength and ductility of thestructural elements. The localized shear failure takes place in the form of localizedpunching and spalling, which produces low and high-speed fragments. The punchingeffect is frequently referred to as “bleaching” (By-field). Bleaching failures aretypically accompanied by spalling and scabbing of concrete covers as well asfragments and debris.

Chapter 3

3.1 Design of Building under seismic loading

The scope of this study is basically to study the response of seismically designed RCC building exposed to blast loading. Although the seismic forces are the governing forces for non high rise RCC framed buildings but still as a matter of sound design practice, effect of wind loading upon the building has also been considered.

Building has been considered to be in earthquake Zone V and effect of blast load is considered over it. In India there had been a number of terrorist activities since independence and most of them are focused in the northern most state of Jammu and Kashmir and as per IS 1893 :2002, Srinagar which is a capital of the state falls under earthquake zone V.

3.1.1 Modeling Building parameters

An RCC framed structure is basically group of different structural elements such as beams, columns, slabs and foundations etc which act in coordination to distribute the loading to the ground in such a way that the stresses induced are within permissible limits. Load distribution takes place from slabs to beams, beams to columns, columns to foundation and finally foundation to soil.

Building under scope of study is a G+4 RCC regular famed building with 4 bays @ 5metre in both the plan dimensions. Storey height of building is kept at 3.3 meter for each storey. Slab at each level has been considered as a diaphragm of thickness 175mm. All the columns have been kept similar with dimensions of the cross section being 550 mm x 550 mm. The beams both primary and secondary have been kept similar with dimensions of cross section being 550mm x 325mm. Infill brick walls in interior of building is kept at 115 mm thick (i.e. Simple partition wall) whereas the outer periphery infill walls are 230 mm thick. Roof of the building has been provided with a 230mm thick and 1.2 m high parapet periphery wall. The base of the building has been kept fixed (i.e. base has been restrained against any kind of rotation and translation). Building dimensions have been taken to be regular and simple, resembling a typical building that could be constructed in India.

The model of building was developed in Etabs Software as shown below (where beam and columns are defined as line frame sections and slab is defined as rigid diaphragm)**:-**

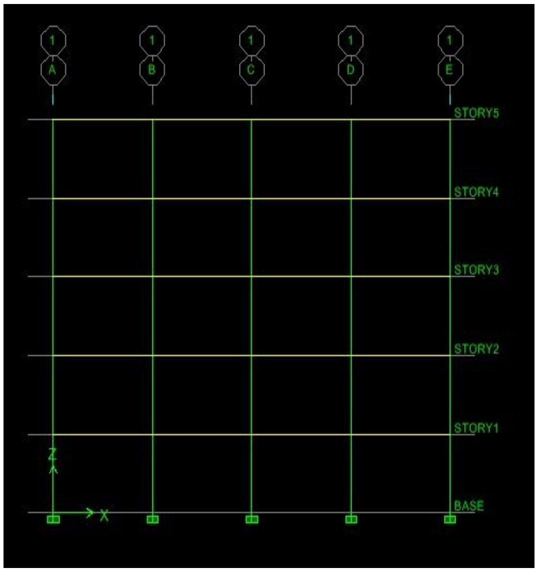


Fig 3.1 Building elevation in Etabs

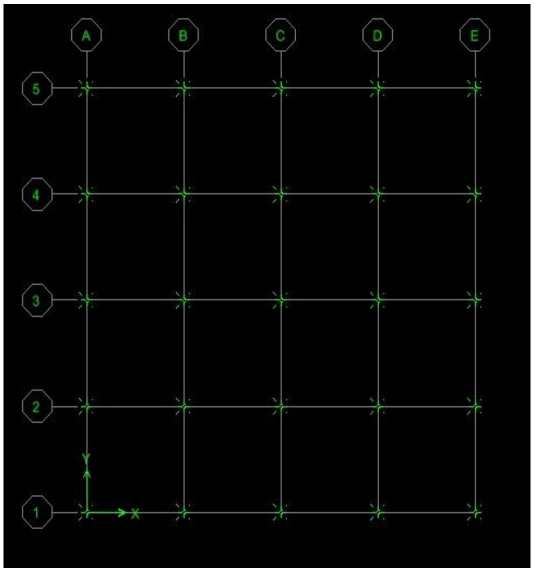


Fig 3.2 Building plan in Etabs

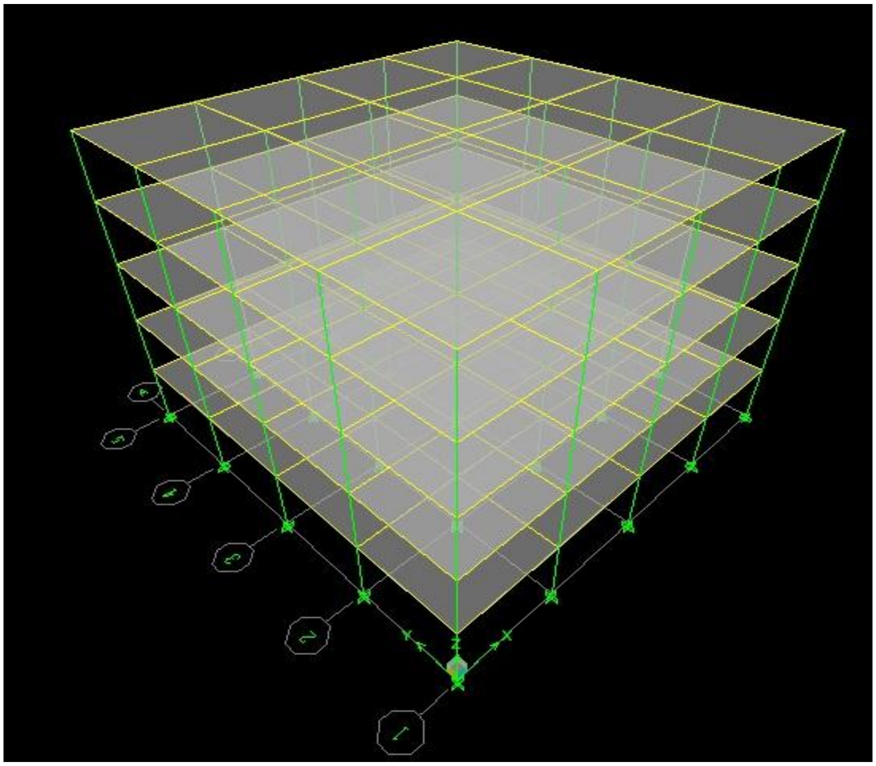


Fig 3.3 3-D building model in Etabs

3.1.2 Assigning Material Properties

For the building under study the following material Properties were assigned:-

1) **Grade of Concrete:-** IS:456-2000 limits the use of minimum grade of concrete to M-25 and the same has been used in our study for complete building.

2) **Grade of steel reinforcement:-** Fe-500 TMT bars have been considered as main tensile and compression reinforcement in building whereas Fe-415 is assigned to shear reinforcement in beams and lateral ties in columns.

3.2 Assigning loads

The following loads have been considered to be acting on the building in accordance with IS: 875 part 1 to 5 as:-

3.2.1 Dead load

Dead load on the structure includes the self weight of beams, columns, slabs, infill walls and other permanent members. The self weight of beams and columns (frame line members) and slabs (area sections) is automatically considered by program itself. However the load of infill wall has been manually calculated and assigned as uniformly distributed loads on the beams. The load has been calculated as:-

Wall load = unit weight of brickwork x thickness of wall x height of wall

Unit weight of brickwork = 20KN/m^3

Thickness of outer periphery wall = 0.23m

Thickness of inner partition wall = 0.115m

Height of wall = 3.3m

Therefore outer periphery wall load = 20*0.23*3.3 = 15.18 KN/m

Therefore inner partition wall load = 20*0.115*3.3 = 7.59 KN/m

Height of parapet wall = 1.2m

Therefore load of parapet wall = 20*0.23*1.2 = 5.52 KN/m

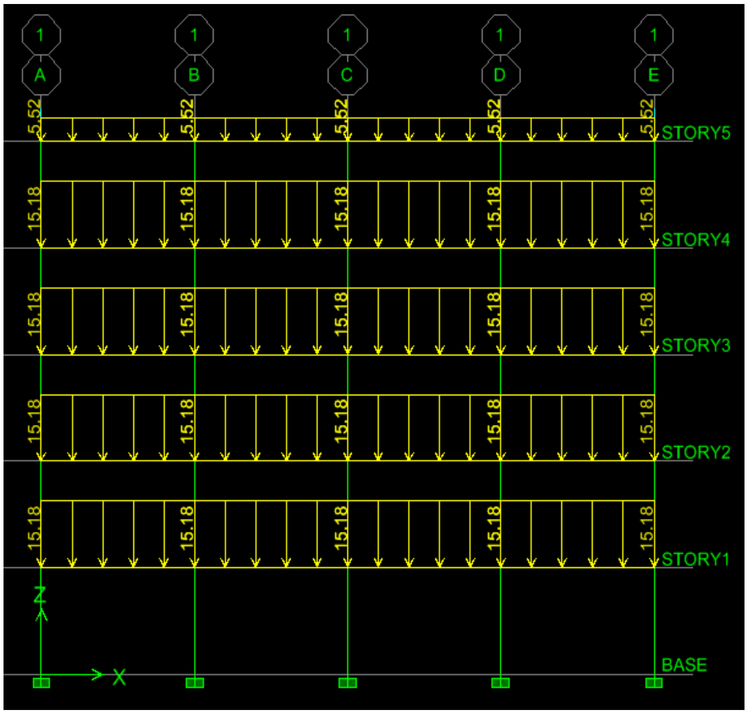


Fig 3.4 External wall load on building

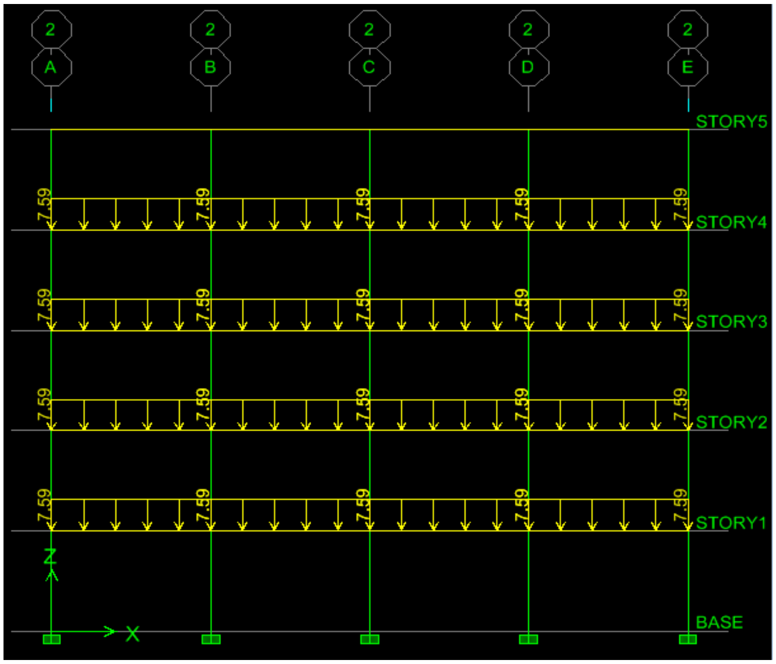


Fig 3.5 Partition wall load on building

3.2.2 Live load

A live load of 3 KN/m^2 has been assigned to all the floors including the roof.

3.2.3 Finished Floor load

A finished floor load of 1.5 KN/m^2has been assigned to all floors except roof which has been assigned a finished floor load of 3 KN/m^2.

3.2.4 Wind Load

Wind load as per IS 875 part 3 has been calculated and applied with values shown in table below

W.L along X axis is applied as shown in table 3 below.

Table 3: Wind load along X direction

STORY	DIAPHRAGM	X ORDINATE	Y ORDINATE	FX (KN)	FY (KN)	MZ (KN-m)
STORY5	D1	10	10	536	0	0
STORY4	D1	10	10	487	0	0
STORY3	D1	10	10	368	0	0
STORY2	D1	10	10	313	0	0
STORY1	D1	10	10	313	0	0

W.L along Y axis is applied as shown in table 4 below.

Table 4: Wind load along Y direction

STORY	DIAPHRAGM	X ORDINATE	Y ORDINATE	FX (KN)	FY (KN)	MZ (KN-m)
STORY5	D1	10	10	0	536	0
STORY4	D1	10	10	0	487	0
STORY3	D1	10	10	0	368	0
STORY2	D1	10	10	0	313	0
STORY1	D1	10	10	0	313	0

3.2.5 Seismic load

Seismic loading on the building is calculated as per provisions of IS: 1893 (part I): 2002. The building in scope of our study is considered to be situated in Zone V with zone factor equal to 0.36 and response reduction factor equal to 5, Importance factor equal to 1.

As per IS: 1893 (part I): 2002, clause 7.6.2 approximate fundamental natural time period of framed RCC building with infill walls is

Ta = 0.09*h/sqrt(d)

Where d is the base dimension of the building at the plinthlevel, in m, along the considered directionof the lateral force.

Thus**,** Ta = 0.09*16.5/sqrt(20) = 0.332 s

Static Load cases EQX and EQY are defined in the software and assigned auto lateral load as per IS 1893: 2002 and Time period equal to 0.332 s as calculated above is assigned.

Besides carrying out static analysis, response spectrum function as per IS 1893:2002 and inbuilt in the software is also used to carry out the dynamic analysis.

3.3 Analysis of building

Load Combinations:- The building is subjected to load combinations shown in table 5 below.

Table 5: Load combinations acting on the building under seismic analysis

Load Combination Id	Combination
COMB1	0.9D.L+0.9 F.F.L-1.5EQx-1.5EQy
DCON1	1.5D.L + 1.5 F.F.L
DCON2	1.5 D.L + 1.5 F.F.L + 1.5 L.L
DCON3	1.2D.L +1.2 F.F.L + 1.2 L.L + 1.2 W.L
DCON4	1.2D.L +1.2 F.F.L + 1.2 L.L- 1.2 W.L
DCON5	1.5 D.L + 1.5 F.F.L + 1.5 W.L
DCON6	1.5 D.L + 1.5 F.F.L - 1.5 W.L
DCON7	0.9 D.L + 0.9 F.F.L + 1.5 W.L
DCON8	0.9 D.L + 0.9 F.F.L - 1.5 W.L
DCON9	1.2D.L +1.2 EQx + 1.2 L.L + 1.2 W.L
DCON10	1.2D.L -1.2 EQx + 1.2 L.L- 1.2 W.L
DCON11	1.2D.L +1.2 EQy + 1.2 L.L + 1.2 W.L
DCON12	1.2D.L -1.2 EQy + 1.2 L.L- 1.2 W.L
DCON13	1.5 D.L + 1.5 F.F.L + 1.5 EQx
DCON14	1.5 D.L + 1.5 F.F.L - 1.5 EQx
DCON15	1.5 D.L + 1.5 F.F.L + 1.5 EQy
DCON16	1.5 D.L + 1.5 F.F.L - 1.5 EQy
DCON17	0.9 D.L + 0.9 F.F.L + 1.5 EQx
DCON18	0.9 D.L + 0.9 F.F.L - 1.5 EQx
DCON19	0.9 D.L + 0.9 F.F.L + 1.5 EQy
DCON20	0.9 D.L + 0.9 F.F.L - 1.5 EQy
DCON21	1.2 D.L + 1.2 F.F.L+1.2 L.L + 1.2 SPEC1 Spectra
DCON22	1.2 D.L + 1.2 F.F.L+1.2 L.L + 1.2 SPEC2

	Spectra
DCON23	1.5 D.L + 1.5 F.F.L + 1.5 SPEC1 Spectra
DCON24	1.5 D.L + 1.5 F.F.L + 1.5 SPEC2 Spectra
DCON25	0.9 D.L + 0.9 F.F.L + 1.5 SPEC1 Spectra
DCON26	0.9 D.L + 0.9 F.F.L + 1.5 SPEC2 Spectra

3.4 Analysis results

3.4.1Maximum story displacements:-Maximum story displacement is tabulated as in table 6.

Table 6: Max. story displacements corresponding to different load cases

Load case	Story	Max. Displacement (mm)
EQx	BASE	0
	FIRST	4.31
	SECOND	11.3
	THIRD	18.21
	FOURTH	23.5
	ROOF	26.91
EQy	BASE	0
	FIRST	4.31
	SECOND	11.3
	THIRD	18.21
	FOURTH	23.5
	ROOF	26.91
W.LX	BASE	0
	FIRST	3.09
	SECOND	7.59
	THIRD	11.65
	FOURTH	14.69
	ROOF	16.48
W.LY	BASE	0
	FIRST	3.09
	SECOND	7.59
	THIRD	11.65
	FOURTH	14.69
	ROOF	16.48
SPEC1	BASE	0
	FIRST	4.37
	SECOND	10.57
	THIRD	16.35

	FOURTH	20.86
	ROOF	23.04
SPEC2	BASE	0
	FIRST	4.37
	SECOND	10.57
	THIRD	16.35
	FOURTH	20.86
	ROOF	23.04

3.4.2Maximum story drift:-Maximum story drift is shown in table 7.

Table 7: Max. story drift corresponding to different load cases

Load case	Story	Max. Drift (mm)
EQx	BASE	0
	FIRST	0.0013
	SECOND	0.002
	THIRD	0.0019
	FOURTH	0.0016
	ROOF	0.0001
EQy	BASE	0
	FIRST	0.0013
	SECOND	0.002
	THIRD	0.0019
	FOURTH	0.0016
	ROOF	0.0001
W.LX	BASE	0
	FIRST	0.0009
	SECOND	0.0014
	THIRD	0.0012
	FOURTH	0.0009
	ROOF	0.0005
W.LY	BASE	0
	FIRST	0.0009
	SECOND	0.0014
	THIRD	0.0012
	FOURTH	0.0009
	ROOF	0.0005
SPEC1	BASE	0
	FIRST	0.0013

	SECOND	0.0019
	THIRD	0.0018
	FOURTH	0.0013
	ROOF	0.0008
SPEC2	BASE	0
	FIRST	0.0013
	SECOND	0.0019
	THIRD	0.0018
	FOURTH	0.0013
	ROOF	0.0008

3.4.3 Mode shape and fundamental time period

First mode shape for both the plan directions of the building were obtained with the fundamental time period of T=0.8131s. The same is shown in the figures below.

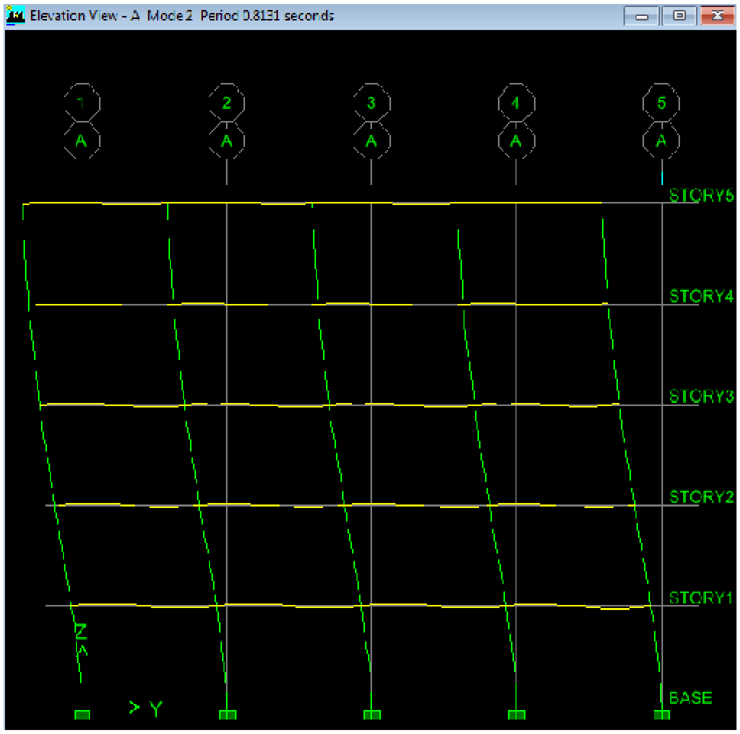


Fig 3.6 Fundamental mode shape in X direction

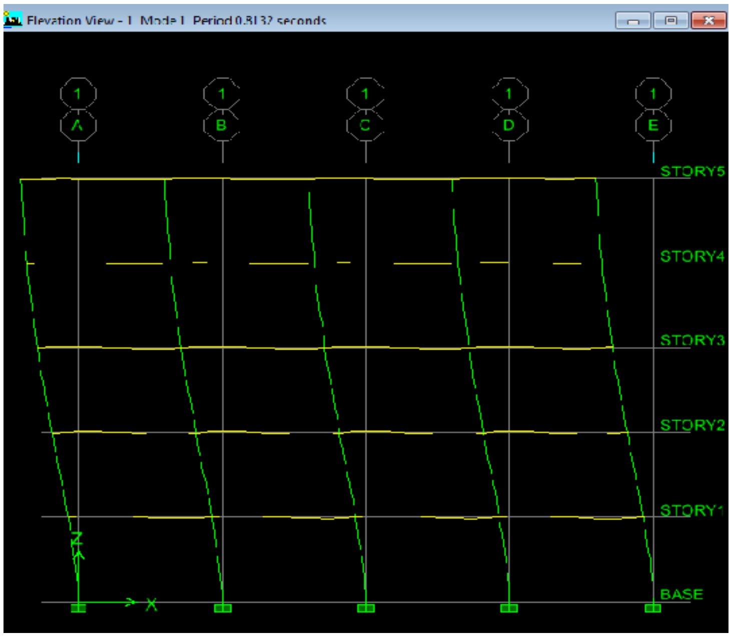


Fig 3.7 Fundamental mode shape in Y direction

3.5 Frame Forces

3.5.1 Maximum shear force in beams

Maximum shear force and corresponding moment in beams is as shown in table 8 below

Table 8 Maximum shear force in beams under seismic design

Story	Beam	Load	Loc	V2 (KN)	T (KN-m)	M3 (KN-m)
STORY2	B23	COMB1	0.275	-174.74	-0.054	-311.441
STORY2	B27	EQX	0.275	79.14	0.035	181.832
STORY2	B27	EQX	0.769	79.14	0.035	142.703
STORY2	B27	EQX	1.264	79.14	0.035	103.573
STORY2	B27	EQX	1.758	79.14	0.035	64.443
STORY2	B27	EQX	2.253	79.14	0.035	25.314
STORY2	B27	EQX	2.747	79.14	0.035	-13.816
STORY2	B27	EQX	3.242	79.14	0.035	-52.945
STORY2	B27	EQX	3.736	79.14	0.035	-92.075
STORY2	B27	EQX	4.231	79.14	0.035	-131.204
STORY2	B27	EQX	4.725	79.14	0.035	-170.334
STORY2	B30	EQX	0.275	79.14	0.035	170.334
STORY2	B30	EQX	0.769	79.14	0.035	131.204
STORY2	B30	EQX	1.264	79.14	0.035	92.075
STORY2	B30	EQX	1.758	79.14	0.035	52.945
STORY2	B30	EQX	2.253	79.14	0.035	13.816

STORY2	B30	EQX	2.747	79.14	0.035	-25.314
STORY2	B30	EQX	3.242	79.14	0.035	-64.443
STORY2	B30	EQX	3.736	79.14	0.035	103.573
STORY2	B30	EQX	4.231	79.14	0.035	-142.703
STORY2	B30	EQX	4.725	79.14	0.035	-181.832

3.5.2 Maximum bending moment in beams

Maximum bending moment (absolute value) and corresponding shear force in beam is shown in table 9 below.

Table 9 Maximum bending moment in beams under seismic design

Story	Beam	Load	Loc	V2 (KN)	T (KN-m)	M3 (KN-m)
STORY2	B23	COMB1	0.275	-174.74	-0.054	-311.441
STORY2	B30	COMB1	4.725	-63.67	-0.089	236.557

3.5.3 Maximum Axial force in column

Maximum Axial force (both compression and tension) and corresponding forces in columns is shown in table 10 below.

Table 10 Maximum Axial force in columns under seismic design

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY1	C2	COMB1	0	-1551.95	-142.65	-144.37	0.164	-375.014	-370.387
STORY1	C44	EQX	0	292.03	89.83	0.63	-0.093	1.47	242.703
STORY1	C44	EQX	1.375	292.03	89.83	0.63	-0.093	0.597	119.182
STORY1	C44	EQX	2.75	292.03	89.83	0.63	-0.093	-0.276	-4.338

3.5.4 Maximum shear force in column

Maximum shear force V2 and corresponding forces in column is shown in table 11 below.

Table 11 Maximum shear force V2 in column under seismic design

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY2	C34	EQX	0	-9.39	126.44	0.19	-0.156	0.356	219.794
STORY2	C34	EQX	1.375	-9.39	126.44	0.19	-0.156	0.096	45.945

STORY2	C34	EQX	2.75	-9.39	126.44	0.19	-0.156	-0.164	-127.904
STORY2	C34	COMB1	0	-438.87	-190.05	-90.16	0.275	-163.791	-330.079
STORY2	C34	COMB1	1.375	-429.51	-190.05	-90.16	0.275	-39.823	-68.76
STORY2	C34	COMB1	2.75	-420.15	-190.05	-90.16	0.275	84.146	192.559
STORY2	C38	EQX	0	9.39	126.44	-0.19	-0.156	-0.356	219.794
STORY2	C38	EQX	1.375	9.39	126.44	-0.19	-0.156	-0.096	45.945
STORY2	C38	EQX	2.75	9.39	126.44	-0.19	-0.156	0.164	-127.9

Maximum shear force V3 and corresponding forces in column is shown in table 12 below.

Table 12 Maximum shear force V3 in columns under seismic design

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY2	C12	EQY	0	-8.67	-0.03	125.87	-0.028	218.788	-0.064
STORY2	C12	EQY	1.375	-8.67	-0.03	125.87	-0.028	45.719	-0.017
STORY2	C12	EQY	2.75	-8.67	-0.03	125.87	-0.028	-127.35	0.029
STORY2	C12	COMB1	0	-1079.08	-124.53	-189.99	0.275	-329.959	-222.382
STORY2	C12	COMB1	1.375	-1069.72	-124.53	-189.99	0.275	-68.723	-51.153
STORY2	C12	COMB1	2.75	-1060.37	-124.53	-189.99	0.275	192.513	120.077
STORY2	C44	EQY	0	8.67	0.03	125.87	-0.028	218.788	0.064
STORY2	C44	EQY	1.375	8.67	0.03	125.87	-0.028	45.719	0.017
STORY2	C44	EQY	2.75	8.67	0.03	125.87	-0.028	-127.35	-0.029

3.5.5 Maximum Moment in column

Maximum Moment M2 and corresponding forces in column is shown in table 13 below.

Table 13 Maximum Moment M2 in column under seismic design

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY1	C12	EQY	0	-13.87	-0.04	117.18	-0.017	271.32	-0.117
STORY1	C44	EQY	0	13.87	0.04	117.18	-0.017	271.32	0.117
STORY1	C44	COMB1	0	-1423.37	-144.44	-176.88	0.164	-409.344	-374.389

Maximum Moment M3 and corresponding forces in column is shown in table 14 below.

Table 14 Maximum Moment M3 in column under seismic design

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY1	C34	EQX	0	-14.76	117.7	0.24	-0.093	0.654	272.527
STORY1	C38	EQX	0	14.76	117.7	-0.24	-0.093	-0.654	272.527
STORY1	C38	COMB1	0	-550.84	-176.86	-124.34	0.164	-351.744	-409.334

Chapter-4

Analysis of building under blast loading

4.1 Modeling of building parameters

Same building model was developed in SAP 2000 software. SAP 2000 software has been used to carry out the pushover analysis.

4.2Calculation of Blast load

Blast loading has been calculated using table 1 of IS code IS: 4991-1968. The blast load is calculated for 100Kg and 500Kg of TNT considering explosion to be at 30m from the face of the building along the centre line of the building.The following steps have been followed to calculate blast loading at a particular beam column joint node:-

1) Calculate the actual distance R of the node from the point of blast, where blast is a surface blast on the ground level.

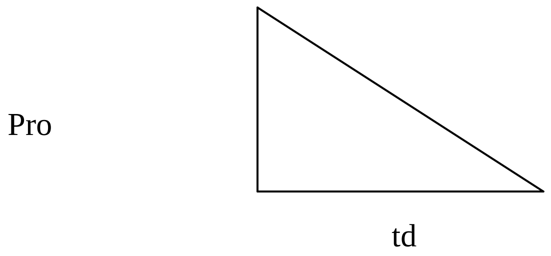
2) Calculate W = yield of explosion in equivalent weight of the reference explosive measured in tones. For 100 Kg and 500 Kg of TNT, W= 0.1 and 0.5 respectively.

3) Using expression 1 of clause 5.3 of IS: 4991-1968, calculate scaled distance Z from the given actual distance R calculated in step 1 above.

4) Using table 1 of IS: 4991-1968, calculate the values of Pso, Pro and qo where all these terms have the meaning as described in code.

5) Using expression 2 of clause 5.3 of IS: 4991-1968, calculate the scaled time to and td.

6) As per clause 8 of IS: 4991-1968, calculate time dependant triangular pressure curve between parameters Pro and td as shown below.



7) Multiply the ordinates of the curve obtained in step 6 with effective area of the node under consideration to obtain a time history curve for loading at node. The effective area for a node under consideration is

8) Blast load is calculated using the steps mentioned above in Microsoft excel sheet and is as shown in table 15 and table 16 below.

Table 15: Blast load acting on various building nodes for 500 Kg TNT.

Force calculation for blast loading										
For 500 Kg TNT										
	W=	100/1000	0.5		Pa =	1kg/cm2				
		Co-ordinates								
Floor	Point	x (m)	y (m)	z (m)	R (m)	Z (m)	T_d (ms)	Pr (kg/cm2)	A (m2)	P (KN)
1	1	-10	30	0	31.62	39.8422	24.94074	1.205963	4.125	488.0081
	2	-5	30	0	30.41	38.319	24.7077	1.50816	8.25	1220.592
	3	0	30	0	30.00	37.79763	24.60425	1.522063	8.25	1231.844
	4	5	30	0	30.41	38.319	24.7077	1.50816	8.25	1220.592
	5	10	30	0	31.62	39.8422	24.94074	1.205963	4.125	488.0081
2	6	-10	30	3.3	31.79	40.05856	24.98424	1.202357	8.25	973.0979
	7	-5	30	3.3	30.59	38.54391	24.75233	1.502162	16.5	2431.475
	8	0	30	3.3	30.18	38.02562	24.64948	1.515983	16.5	2453.847
	9	5	30	3.3	30.59	38.54391	24.75233	1.502162	16.5	2431.475
	10	10	30	3.3	31.79	40.05856	24.98424	1.202357	8.25	973.0979
3	11	-10	30	6.6	32.30	40.70072	25.18823	1.191655	8.25	964.436
	12	-5	30	6.6	31.12	39.21088	24.8138	1.216485	16.5	1969.064
	13	0	30	6.6	30.72	38.70153	24.71138	1.224975	16.5	1982.805
	14	5	30	6.6	31.12	39.21088	24.8138	1.216485	16.5	1969.064
	15	10	30	6.6	32.30	40.70072	25.18823	1.191655	8.25	964.436
4	16	-10	30	9.9	33.14	41.74904	25.39624	1.174183	8.25	950.2954
	17	-5	30	9.9	31.98	40.29798	25.03238	1.198367	16.5	1939.737
	18	0	30	9.9	31.59	39.80254	24.93276	1.206624	16.5	1953.102
	19	5	30	9.9	31.98	40.29798	25.03238	1.198367	16.5	1939.737
	20	10	30	9.9	33.14	41.74904	25.39624	1.174183	8.25	950.2954
5	21	-10	30	13.2	34.27	43.17395	25.60272	1.150434	8.25	931.0752
	22	-5	30	13.2	33.15	41.77242	25.40088	1.173793	16.5	1899.96
	23	0	30	13.2	32.78	41.29467	25.30608	1.181756	16.5	1912.849
	24	5	30	13.2	33.15	41.77242	25.40088	1.173793	16.5	1899.96
	25	10	30	13.2	34.27	43.17395	25.60272	1.150434	8.25	931.0752

Table 16: Blast load acting on various building nodes for 100 Kg TNT.

For 100 Kg TNT										
	W=	100/1000	0.1		Pa =	1kg/cm2				
		Co-ordinates								
Floor	Point	x (m)	y (m)	z (m)	R (m)	Z (m)	Td (ms)	Pr (kg/cm2)	A (m2)	P (KN)
1	1	-10	30	0	31.62278	68.12921	17.91161	0.734513	4.125	297.23
	2	-5	30	0	30.41381	65.52457	17.60608	0.782678	8.25	633.4409
	3	0	30	0	30	64.63304	17.50262	0.806452	8.25	652.682
	4	5	30	0	30.41381	65.52457	17.60608	0.782678	8.25	633.4409
	5	10	30	0	31.62278	68.12921	17.91161	0.734513	4.125	297.23
2	6	-10	30	3.3	31.7945	68.49917	17.95511	0.728347	8.25	589.4696
	7	-5	30	3.3	30.59232	65.90915	17.6507	0.772423	16.5	1250.282
	8	0	30	3.3	30.18095	65.02289	17.54786	0.796056	16.5	1288.536
	9	5	30	3.3	30.59232	65.90915	17.6507	0.772423	16.5	1250.282
	10	10	30	3.3	31.7945	68.49917	17.95511	0.728347	8.25	589.4696
3	11	-10	30	6.6	32.30418	69.59724	18.08331	0.710046	8.25	574.6579
	12	-5	30	6.6	31.1217	67.04966	17.78467	0.752506	16.5	1218.043
	13	0	30	6.6	30.71742	66.17868	17.68226	0.767022	16.5	1241.54
	14	5	30	6.6	31.1217	67.04966	17.78467	0.752506	16.5	1218.043
	15	10	30	6.6	32.30418	69.59724	18.08331	0.710046	8.25	574.6579
4	16	-10	30	9.9	33.13623	71.38985	18.29132	0.680169	8.25	550.4779
	17	-5	30	9.9	31.98453	68.90858	18.00326	0.721524	16.5	1167.894
	18	0	30	9.9	31.5913	68.06138	17.90364	0.735644	16.5	1190.749
	19	5	30	9.9	31.98453	68.90858	18.00326	0.721524	16.5	1167.894
	20	10	30	9.9	33.13623	71.38985	18.29132	0.680169	8.25	550.4779
5	21	-10	30	13.2	34.26719	73.82641	18.57689	0.63956	8.25	517.6117
	22	-5	30	13.2	33.15479	71.42983	18.29596	0.679503	16.5	1099.877
	23	0	30	13.2	32.7756	70.61289	18.20117	0.693118	16.5	1121.916
	24	5	30	13.2	33.15479	71.42983	18.29596	0.679503	16.5	1099.877
	25	10	30	13.2	34.26719	73.82641	18.57689	0.63956	8.25	517.6117

4.3 Assigning loads

The blast loading calculated in table 8 and 9 above for 500 kg and 100 kg TNT explosive, is assigned as a time history loading to the model and non-linear response of building is studied in SAP 2000 V 18 software for both the charge weights differently. The time history function having name FUNC2 is defined and used for two separate SAP models for separate charge weights respectively.

4.4 Analysis of building

Two separate analysis of building models are carried out. The first analysis involves running all the load cases except the blast and pushover cases. This is done to ensure that model prepared in Etabs and SAP is structurally similar without much variation. After we obtain almost the same building response parameters viz fundamental time period and frame forces, the second analysis is carried out which is also known as pushover analysis. The pushover analysis is carried out to study the formation of hinges and judge the performance level and occupancy level of building just after the pushover analysis.

The response of building is studied for two different charge weights of 500Kg and 100 Kg TNT respectively. This is to study the variation in response parameters for different weights of TNT and with seismic forces as well.

4.5 Analysis results for 500 kg TNT

Blast force is calculated as shown in table 15 above and the loading is applied as a time history function in the SAP 2000 V 18 model. The following building responses were observed:

4.5.1 Story displacements

Story displacements are shown in table 17 below

Table 17 Maximum story displacementsunder blast analysis (500 kg TNT)

Load case	Story	Max. Displacement (mm)
EQx	BASE	0
	FIRST	4.25
	SECOND	11.17
	THIRD	18.11
	FOURTH	23.23
	ROOF	26.75
EQy	BASE	0
	FIRST	4.25

	SECOND	11.17
	THIRD	18.11
	FOURTH	23.23
	ROOF	26.75
W.LX	BASE	0
	FIRST	2.97
	SECOND	7.49
	THIRD	11.57
	FOURTH	14.58
	ROOF	16.39
W.LY	BASE	0
	FIRST	2.97
	SECOND	7.49
	THIRD	11.57
	FOURTH	14.58
	ROOF	16.39
SPEC1	BASE	0
	FIRST	4.28
	SECOND	10.47
	THIRD	16.28
	FOURTH	20.78
	ROOF	22.96
SPEC2	BASE	0
	FIRST	4.28
	SECOND	10.47
	THIRD	16.28
	FOURTH	20.78
	ROOF	22.96
FUNC2	BASE	0
	FIRST	170.9
	SECOND	461.3
	THIRD	-764.4
	FOURTH	-990.6
	ROOF	-1255.1

4.5.2 Story drift

Maximum story drift for the building isshown in table 18 below.

Table 18 Maximum story drift under blast analysis (500 kg TNT)

Load case	Story	Max. Drift (mm)
EQx	BASE	0
	FIRST	0.0013
	SECOND	0.0021
	THIRD	0.0021
	FOURTH	0.0015
	ROOF	0.0010
EQy	BASE	0
	FIRST	0.0013
	SECOND	0.0021
	THIRD	0.0021
	FOURTH	0.0015
	ROOF	0.0010
W.LX	BASE	0
	FIRST	0.0009
	SECOND	0.0014
	THIRD	0.0012
	FOURTH	0.0009
	ROOF	0.0005
W.LY	BASE	0
	FIRST	0.0009
	SECOND	0.0014
	THIRD	0.0012
	FOURTH	0.0009
	ROOF	0.0005
SPEC1	BASE	0
	FIRST	0.0013
	SECOND	0.0018
	THIRD	0.0058
	FOURTH	0.0013
	ROOF	0.0006
SPEC2	BASE	0
	FIRST	0.0013
	SECOND	0.0018
	THIRD	0.0058

	FOURTH	0.0013
	ROOF	0.0006
FUNC2	BASE	0
	FIRST	0.051
	SECOND	0.29
	THIRD	-0.37
	FOURTH	-0.068
	ROOF	-0.08

4.5.3 Mode shape and fundamental mode

Mode shape for the fundamental mode and corresponding fundamental time period of 0.98133s is observed as shown in fig4.1 below

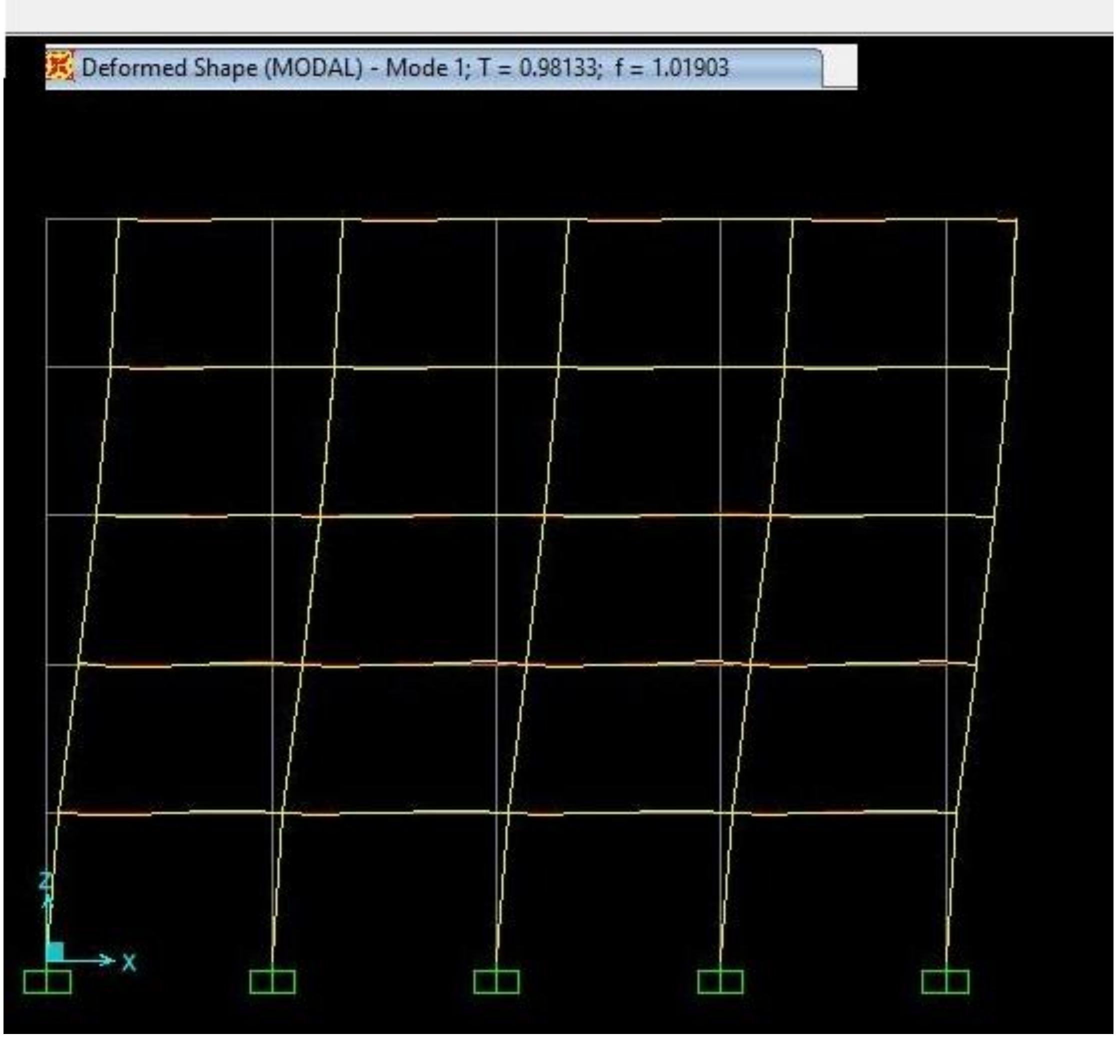


Fig 4.1 Fundamental mode and time period under blast loading (500 kg TNT)

4.5.4 Frame forces

Frame forces (Maximum magnitude) corresponding to seismic design using Etabs software were shown in chapter 3. For the members having maximum forces in chapter 3, frame forces for 500 Kg TNT induced blast loading is shown below.

4.5.4.1 Shear force in beams

Maximum shear force and corresponding moment in beamsis as shown in table 19 below

Table 19 Maximum shear force in beams under blast analysis (500 kg TNT)

Story	Element	Load	Loc	V2 (KN)	T (KN-m)	M3 (KN-m)
STORY2	469	COMB1	0.275	-174.74	-0.054	-311.441
STORY2	453	FUNC2	4.167	1589.958	205.894	1497.054
STORY2	453	FUNC2	4.58	1589.958	205.894	2126.877
STORY2	453	FUNC2	5	1589.958	205.894	2756.7
STORY2	456	FUNC2	0.275	1589.955	205.894	2905.1
STORY2	456	FUNC2	0.769	1589.955	205.894	2242.62
STORY2	456	FUNC2	1.264	1589.955	205.894	1580.134

4.5.4.2 Bending Moment in beams

Maximum bending moment and corresponding shear force in beams is shown in table 20 below

Table 20 Maximum bending moment in beams under blast analysis (500 kg TNT)

Story	Beam	Load	Loc	V2 (KN)	T (KN-m)	M3 (KN-m)
STORY2	469	FUNC2	0	1674.893	0.9256	-2905.2588
STORY2	456	FUNC2	0	1589.955	205.8932	2905.09

4.5.4.3 Axial forces in columns

Maximum Axial force (both compression and tension) and corresponding forces in columns is shown in table 21 below.

Table 21 Maximum Axial force in column under blast analysis (500 kg TNT)

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY1	493	FUNC2	0	-6546.6	-2799.28	-63.288	0.00	66.83	8940.69
STORY1	493	FUNC2	1.65	6546.6	2799.28	63.288	0.00	34.88	4321.87
STORY1	493	FUNC2	3.3	6546.6	2799.28	63.288	0.00	131.77	789.695

STORY1	669	FUNC2	0	8529.31	3039.587	2.737	0.00	2.89	9194.45
STORY1	669	FUNC2	1.65	8529.31	3039.587	2.737	0.00	1.582	4179.13
STORY1	669	FUNC2	3.3	8529.31	3039.587	2.737	0.00	5.96	1239.20

4.5.4.4 Shear forces in columns

Maximum shear force V2 and corresponding forces in column is shown in table 22 below.

Table 22 Maximum shear force V2 in columns under blast analysis (500 kg TNT)

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY2	700	FUNC2	0	366.008	3481.4	18.06	0.00	30.11	5964
STORY2	700	FUNC2	1.65	366.008	3481.4	18.06	0.00	1.02	1050
STORY2	700	FUNC2	3.3	366.008	3481.4	18.06	0.00	30.07	5327
STORY2	700	FUNC2	0	-306.784	-3272.74	-17.6	0.00	-28.05	-6401
STORY2	700	FUNC2	1.65	-306.784	-3272.74	-17.6	0.00	-1.74	-1009
STORY2	700	FUNC2	3.3	-306.784	-3272.74	-17.6	0.00	-29.5	-5524
STORY2	710	FUNC2	0	306.783	3481.4	17.6	0.00	28.05	5964
STORY2	710	FUNC2	1.65	306.783	3481.4	17.6	0.00	1.70	1049.74
STORY2	710	FUNC2	3.3	306.783	3481.4	17.6	0.00	29.5	5327

Maximum shear force V3 and corresponding forces in column

The maximum shear force V3 and corresponding forces in columns is same as that for earthquake loading.

4.5.4.5 Moment in columns

Maximum Moment M2 and corresponding forces in column is shown in table 23 below.

Table 23 Maximum Moment M2 in columns under blast analysis (500 kg TNT)

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY1	544	MODAL	0	391.45	122.7	1461.7	0.00	2396.7	202.53
STORY1	669	MODAL	0	-370.4	123.49	1461.7	0.00	2396.7	202.98

Maximum Moment M3 and corresponding forces in column is shown in table 24 below.

Table 24 Maximum Moment M3 in column under blast analysis (500 kg TNT)

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY1	669	FUNC2	0	8529.31	3039.58	2.74	0.00	2.88	9194.45
STORY1	709	FUNC2	0	378.615	3444.02	8.528	0.00	8.72	9621.54

4.6 Analysis results for 100 kg TNT

Blast force is calculated as shown in table 9 above and the loading is applied as a time history function in the SAP 2000 V 18 model. The following building responses were observed:

4.6.1 Story displacements:

Story displacements are shown in table 25 below

Table 25Maximum story displacements forblast analysis (100 kg TNT)

Load case	Story	Max. Displacement (mm)
EQx	BASE	0
	FIRST	4.25
	SECOND	11.17
	THIRD	18.11
	FOURTH	23.23
	ROOF	26.75
EQy	BASE	0
	FIRST	4.25
	SECOND	11.17
	THIRD	18.11
	FOURTH	23.23
	ROOF	26.75
W.LX	BASE	0
	FIRST	2.97
	SECOND	7.49
	THIRD	11.57
	FOURTH	14.58
	ROOF	16.39
W.LY	BASE	0
	FIRST	2.97
	SECOND	7.49

	THIRD	11.57
	FOURTH	14.58
	ROOF	16.39
SPEC1	BASE	0
	FIRST	4.28
	SECOND	10.47
	THIRD	16.28
	FOURTH	20.78
	ROOF	22.96
SPEC2	BASE	0
	FIRST	4.28
	SECOND	10.47
	THIRD	16.28
	FOURTH	20.78
	ROOF	22.96
FUNC2	BASE	0
	FIRST	74.5
	SECOND	201.4
	THIRD	-333.5
	FOURTH	-434.6
	ROOF	-552.9

4.6.2 Story drift

Maximum story drift for the building is shown in table 26 below.

Table 26 Maximum story drift under blast analysis (100 kg TNT)

Load case	Story	Max. Displacement (mm)
EQx	BASE	0
	FIRST	0.0013
	SECOND	0.0021
	THIRD	0.0021
	FOURTH	0.0015
	ROOF	0.0010
EQy	BASE	0
	FIRST	0.0013
	SECOND	0.0021
	THIRD	0.0021
	FOURTH	0.0015
	ROOF	0.0010
W.LX	BASE	0

	FIRST	0.0009
	SECOND	0.0014
	THIRD	0.0012
	FOURTH	0.0009
	ROOF	0.0005
W.LY	BASE	0
	FIRST	0.0009
	SECOND	0.0014
	THIRD	0.0012
	FOURTH	0.0009
	ROOF	0.0005
SPEC1	BASE	0
	FIRST	0.0013
	SECOND	0.0018
	THIRD	0.0058
	FOURTH	0.0013
	ROOF	0.0006
SPEC2	BASE	0
	FIRST	0.0013
	SECOND	0.0018
	THIRD	0.0058
	FOURTH	0.0013
	ROOF	0.0006
FUNC2	BASE	0
	FIRST	0.022
	SECOND	0.038
	THIRD	-0.162
	FOURTH	-0.03
	ROOF	-0.035

4.6.3 Mode shape and Fundamental time period

Mode shape for the fundamental mode and corresponding fundamental time period of 0.98133s is observed as shown in fig 4.2 below

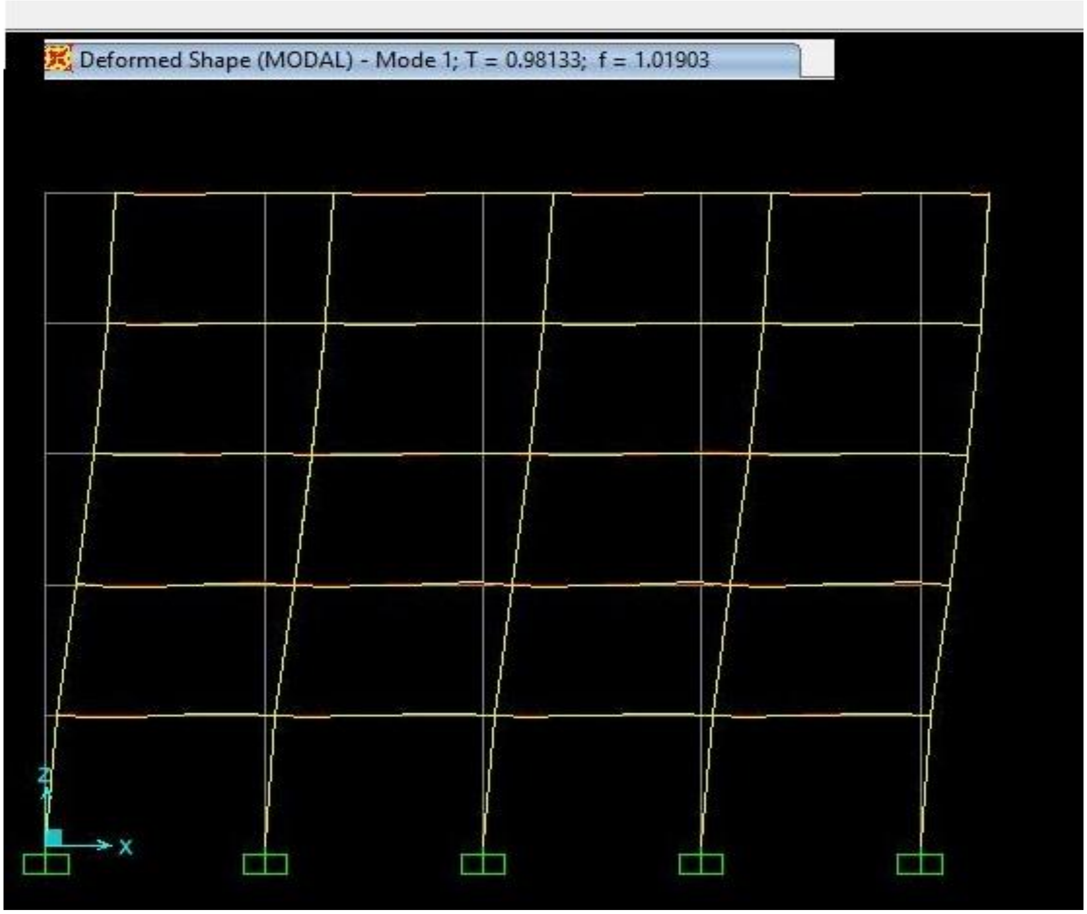

Deformed Shape (MODAL) - Mode 1; T = 0.98133; f = 1.01903

Fig 4.2 Fundamental mode and time period for blast analysis (100 kg TNT)

4.6.4 Frame forces

Frame forces (Maximum magnitude) corresponding to seismic design using Etabs software were shown in chapter 3. For the members having maximum forces in chapter 3, frame forces for 100 Kg TNT induced blast loading is shown below.

4.6.4.1 Shear force in beams

Maximum shear force and corresponding moment in beams (same as that under earthquake loads) is as shown in table 27 below

Table 27 Maximum shear force in beams under blast analysis (100 kg TNT)

Story	Element	Load	Loc	V2 (KN)	T (KN-m)	M3 (KN-m)
STORY2	469	COMB1	0.275	-68.74	0.00	-111.441
STORY2	453	FUNC2	4.167	694.059	91.366	644.54
STORY2	453	FUNC2	4.58	694.059	91.366	944.02

STORY2	453	FUNC2	5	694.059	91.366	1223.5
STORY2	456	FUNC2	0.275	694.059	91.366	1268.159
STORY2	456	FUNC2	0.769	694.059	91.366	978.968
STORY2	456	FUNC2	1.264	694.059	91.366	689.775

4.6.4.2 Bending Moment in beams

Maximum bending moment and corresponding shear force in beam is shown in table 28 below.

Table 28 Maximum bending moment in beams under blast analysis (100 kg TNT)

Story	Beam	Load	Loc	V2 (KN)	T (KN-m)	M3 (KN-m)
STORY2	469	FUNC2	0	851.311	0.6813	1271.55
STORY2	456	FUNC2	0	694.058	91.366	1268.16

4.6.4.3 Axial forces in columns

Maximum Axial force (both compression and tension) and corresponding forces in column is shown in table 29 below.

Table 29Maximum Axial force in column under blast analysis (100 kg TNT)

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY1	493	FUNC2	0	2869.73	1216.434	27.62	0.00	29.16	3893.6
STORY1	493	FUNC2	1.65	2869.73	1216.434	27.62	0.00	15.54	1886.48
STORY1	493	FUNC2	3.3	2869.73	1216.434	27.62	0.00	58.73	327.21
STORY1	669	FUNC2	0	3738.11	1321.3	1.198	0.00	1.2655	4004.34
STORY1	669	FUNC2	1.65	3738.11	1321.3	1.198	0.00	0.667	1824.18
STORY1	669	FUNC2	3.3	3738.11	1321.3	1.198	0.00	2.5186	526.31

4.6.4.4 Shear forces in columns

Maximum shear force V2 and corresponding forces in column is shown in table 30 below.

Table 30Maximum shear force V2 in columns under blast analysis (100 kg TNT)

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY2	700	FUNC2	0	152.14	1525.05	7.922	0.00	13.18	2612.7

STORY2	700	FUNC2	1.65	152.14	1525.05	7.922	0.00	0.44	438.04
STORY2	700	FUNC2	3.3	152.14	1525.05	7.922	0.00	12.52	2258.1
STORY2	700	FUNC2	0	-135.27	-1415.2	-7.38	0.00	-11.86	-2724.6
STORY2	700	FUNC2	1.65	-135.27	-1415.2	-7.38	0.00	-0.91	-389.44
STORY2	700	FUNC2	3.3	-135.27	-1415.2	-7.38	0.00	-12.96	-2419.9
STORY2	710	FUNC2	0	135.272	1525.05	7.38	0.00	11.86	2612.78
STORY2	710	FUNC2	1.65	135.272	1525.05	7.38	0.00	0.92	438.04
STORY2	710	FUNC2	3.3	135.272	1525.05	7.38	0.00	12.96	2258.12

Maximum shear force V3 and corresponding forces in column

The maximum shear force V3 and corresponding forces in columns is same as that for earthquake loading.

4.6.4.5 Moment in columns

Maximum Moment M2 and corresponding forces in column is shown in table 31 below.

Table 31Maximum moment M2 in columns under blast analysis (100 kg TNT)

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY1	544	MODAL	0	391.45	122.7	1461.7	0.00	2396.7	202.53
STORY1	669	MODAL	0	-370.4	123.49	1461.7	0.00	2396.7	202.98

Maximum Moment M3 and corresponding forces in column is shown in table 32 below.

Table 32Maximum moment M3 in columns under blast analysis (100 kg TNT)

Story	Column	Load	Loc	P (KN)	V2 (KN)	V3 (KN)	T (KN-m)	M2 (KN-m)	M3 (KN-m)
STORY1	669	FUNC2	0	3738.11	1321.3	1.19	0.00	1.26	4004.34
STORY1	709	FUNC2	0	167.7	1497.7	3.59	0.00	3.79	4190.65

Chapter 5

Comparison of building response and conclusions

The aim of this study is to analyze the response of G+4 RCC building for TNT induced blast loading with different charge weights at same standoff distance of 30 m. The building however has been already analyzed and designed for seismic loading considerations as has been shown in chapter 3 above. The building parameters and responses could thus be compared easily after the analysis for blast loading carried out in chapter 4. The different comparisons and their respective conclusions has been mentioned in this chapter and are as follows.

5.1 Comparison of story displacement and drift for seismic and blast loading.

Conclusion 1

The displacement of building related to blast loading is different from that of earthquake loading, i.e. the building does not behaves as a cantilever as it does in the case of earthquake.

Conclusion 2

The story displacements and drift values are more for more charge weight of similar explosive when blasted at same stand-off distances from the building.

Conclusion 3

The story displacements and drift for blast loading, far exceed their allowable values when compared with allowable values mentioned in IS 1893: 2002 for earthquake loading.

5.2 Comparison of frame forces for seismic and blast loading

Conclusion 4

From Tables 8, 19 and 27 showing values of maximum shear force in beams, it can be concluded that blast loading results in increase in value to 10 and 20 times for 100 kg and 500 kg TNT explosive respectively over that for seismic design.

Conclusion 5

From Tables 9, 20 and 28 showing values of maximum bending moments in beams, it can be concluded that blast loading results in increase in value to 5 and 10 times for 100 kg and 500 kg TNT explosive respectively over that for seismic design.

Conclusion 6

From Tables 10, 21 and 29 showing values of maximum axial force in columns, it can be concluded that blast loading results in increase in value to 2 and 4 times for 100 kg and 500 kg TNT explosive respectively over that for seismic design.

Conclusion 7

From Tables 11, 22 and 30 showing values of maximum shear force V2 in columns, it can be concluded that blast loading results in increase in value to 10 and 20 times for 100 kg and 500 kg TNT explosive respectively over that for seismic design.

Conclusion 8

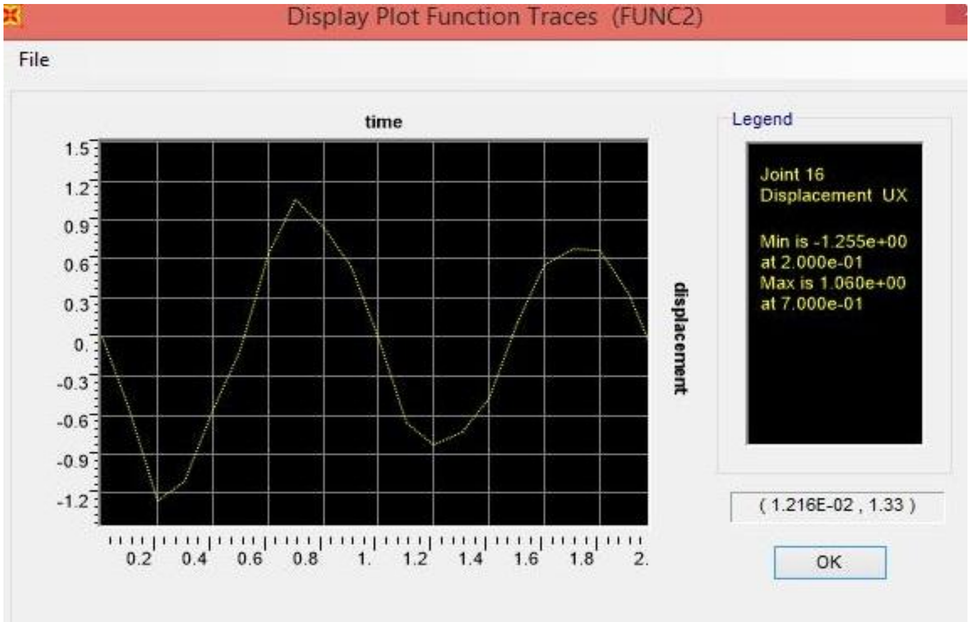
From Tables 14, 24 and 32 showing values of maximum moment M3 in columns, it can be concluded that blast loading results in increase in value to 12 and 24 times for 100 kg and 500 kg TNT explosive respectively over that for seismic design.

Thus it could also be concluded that the increase in forces in members (having maximum forces in seismic design) is roughly twice for 500 kg TNT over that of 100 kg TNT for explosions at same standoff distance of 30m.

Thus as a generalization it could be assumed that the impact of blast loading increases with the increase in charge weight at same standoff distance but not in a direct proportion.

5.3 Comparison of joint displacement, velocity and acceleration parameters for different charge weight.

Joint Displacement Curves for 500 kg and 100 kg TNT

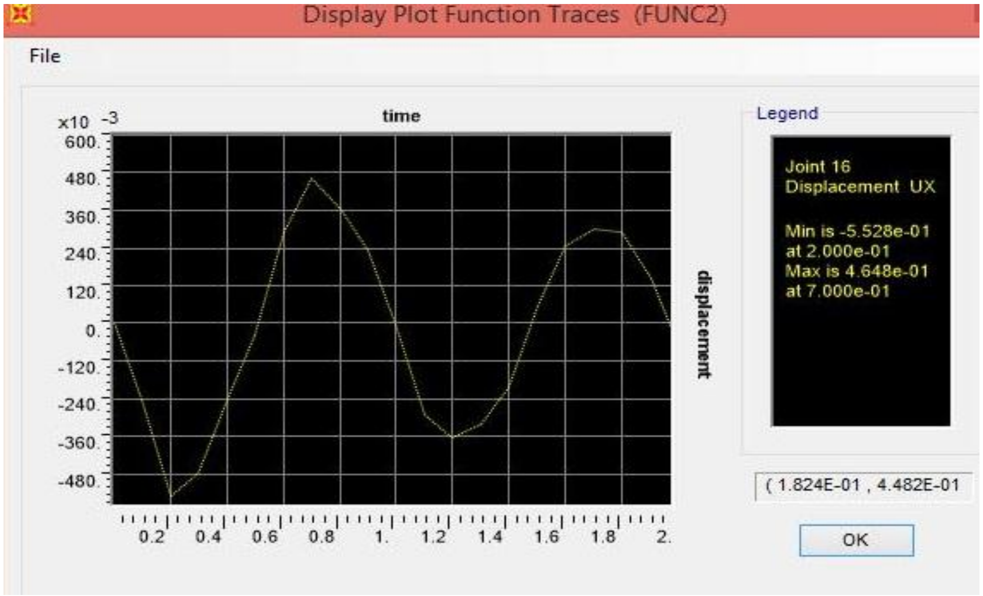


Joint 16
Displacement UX

Min is -1.255e+00
at 2.000e-01
Max is 1.060e+00
at 7.000e-01

(1.216E-02 , 1.33)

Fig 5.1 Joint Displacement Curve for 500 Kg TNT



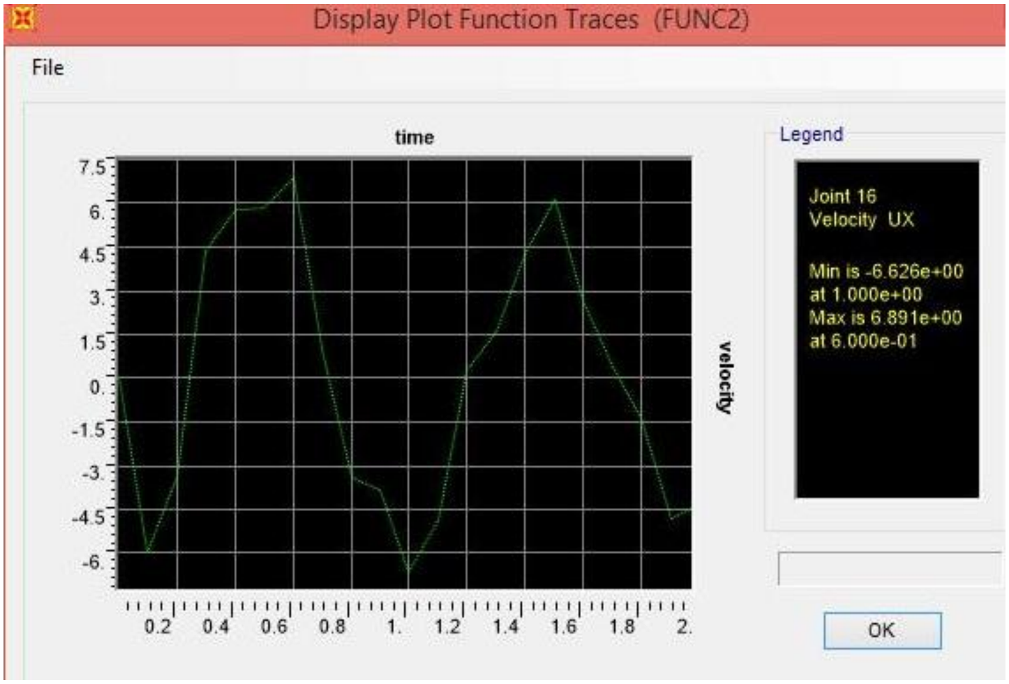
Joint 16
Displacement UX

Min is -5.528e-01
at 2.000e-01
Max is 4.648e-01
at 7.000e-01

(1.824E-01 , 4.482E-01)

Fig 5.2 Joint displacement curve for 100 kg TNT

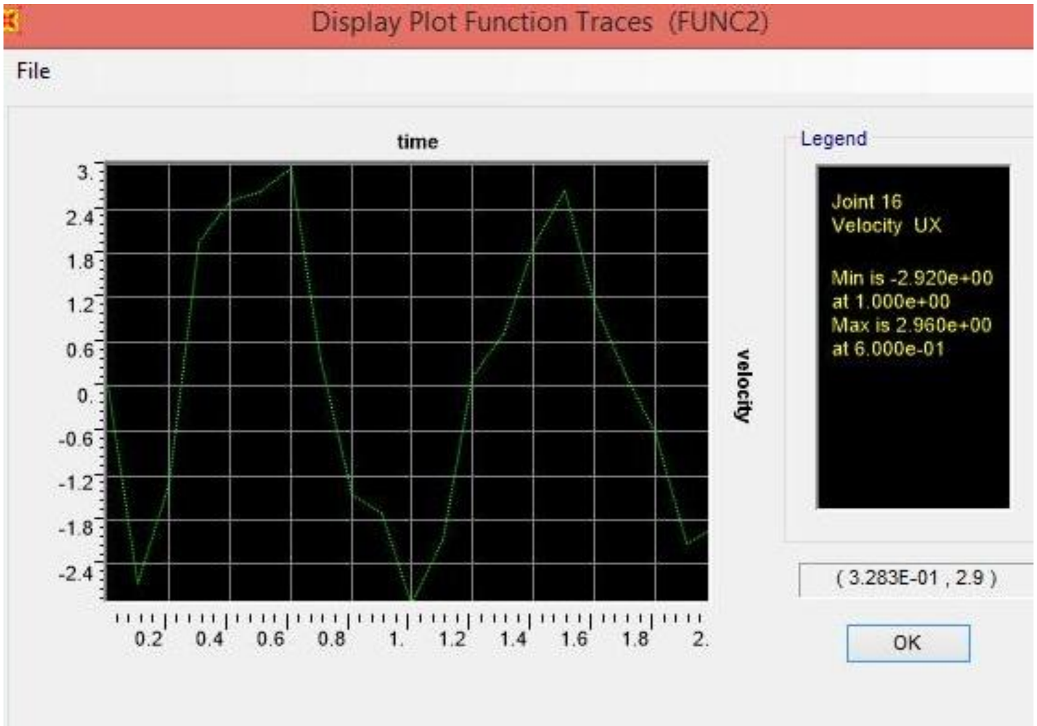
Joint velocity curves for 500 kg and 100 kg TNT



Joint 16
Velocity UX

Min is -6.626e+00
at 1.000e+00
Max is 6.891e+00
at 6.000e-01

Fig 5.3 Joint velocity curve for 500 kg TNT



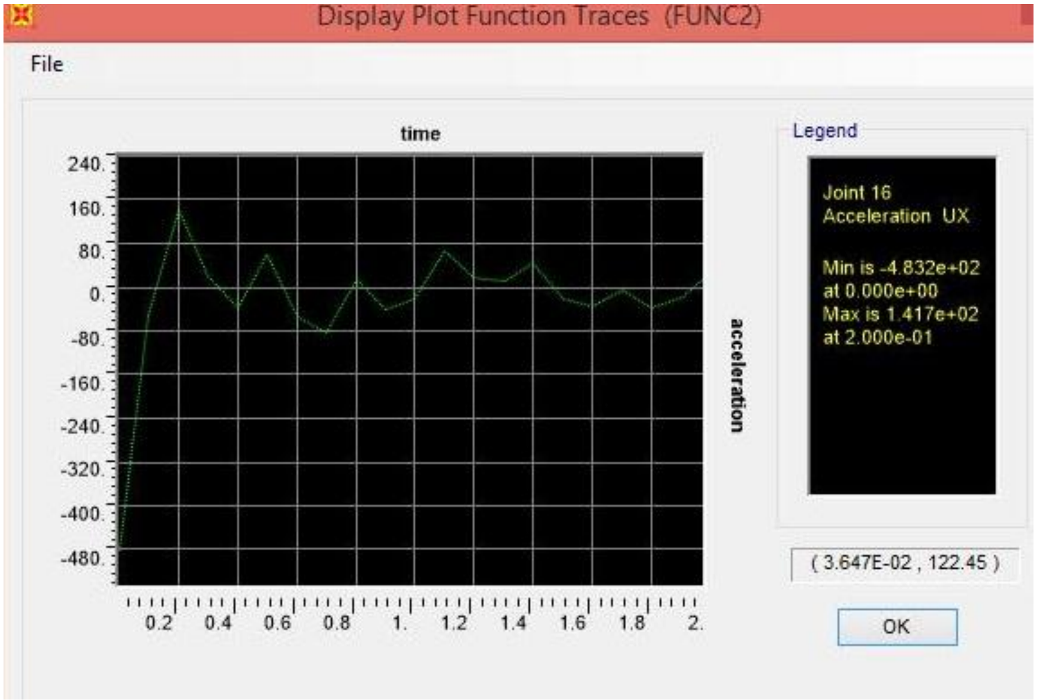
Joint 16
Velocity UX

Min is -2.920e+00
at 1.000e+00
Max is 2.960e+00
at 6.000e-01

(3.283E-01 , 2.9)

Fig 5.4 Joint velocity curve for 100 kg TNT

Joint acceleration curves for 50 Kg and 100 kg TNT

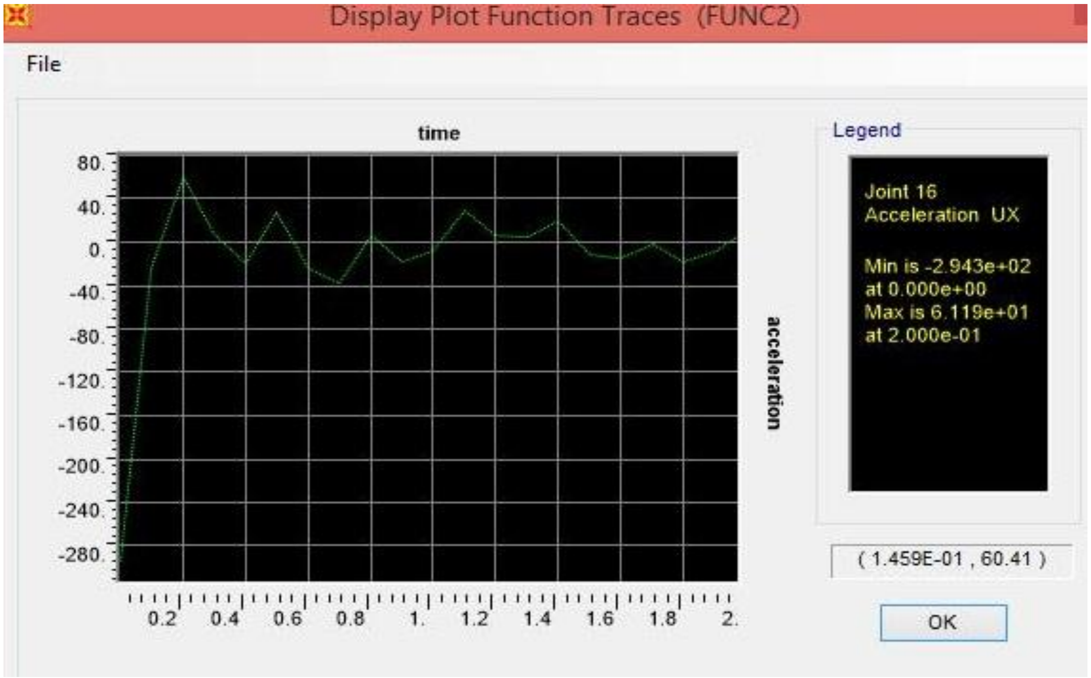


Joint 16
Acceleration UX

Min is -4.832e+02
at 0.000e+00
Max is 1.417e+02
at 2.000e-01

(3.647E-02 , 122.45)

Fig 5.5 Joint acceleration curves for 500 kg TNT



Joint 16
Acceleration UX

Min is -2.943e+02
at 0.000e+00
Max is 6.119e+01
at 2.000e-01

(1.459E-01 , 60.41)

Fig 5.6 Joint acceleration curves for 100 kg TNT

Conclusion 9

Parameter	Explosive weight		% increase
	100 kg	500 kg	
Joint displacement	0.48 m	1.02 m	112
Joint velocity	3 m/s	6.9 m/s	130
Joint acceleration	52 m/s2	130 m/s2	150

Conclusion 10

From figures 5.7 and 5.8 showing static pushover curves for building subjected to blast loading of 500 kg and 1000 kg TNT at a standoff distance of 30 m respectively, it can be concluded that the building id safe for both the explosions as the hinges formed at the base are of life safety level and that at all other locations are of immediate occupancy level.

Static Pushover curves for 500 kg and 100 kg TNT

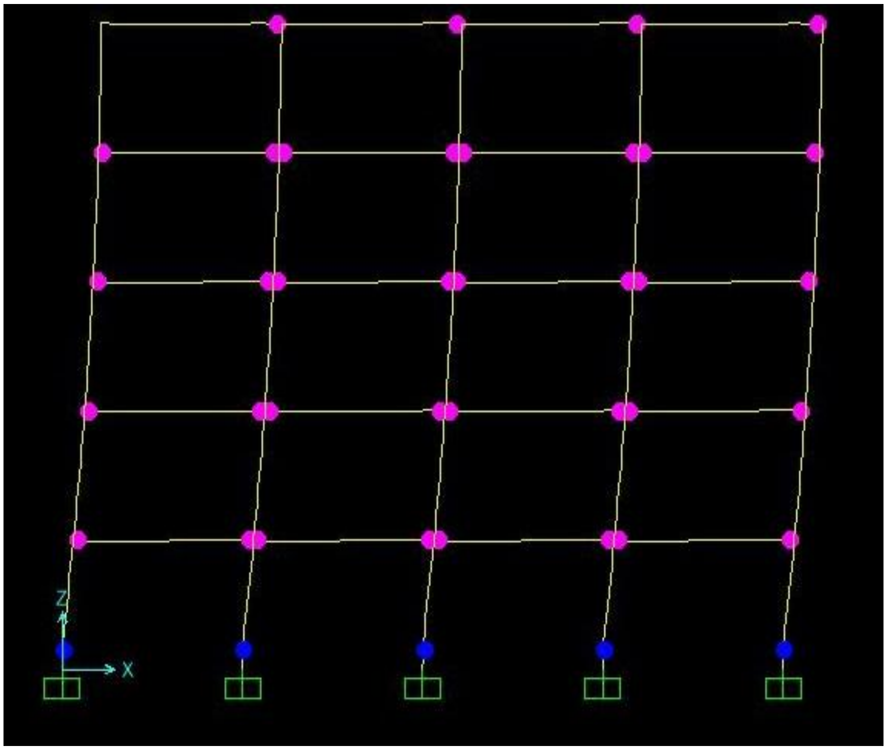


Fig 5.7 Pushover curve for 500 kg TNT

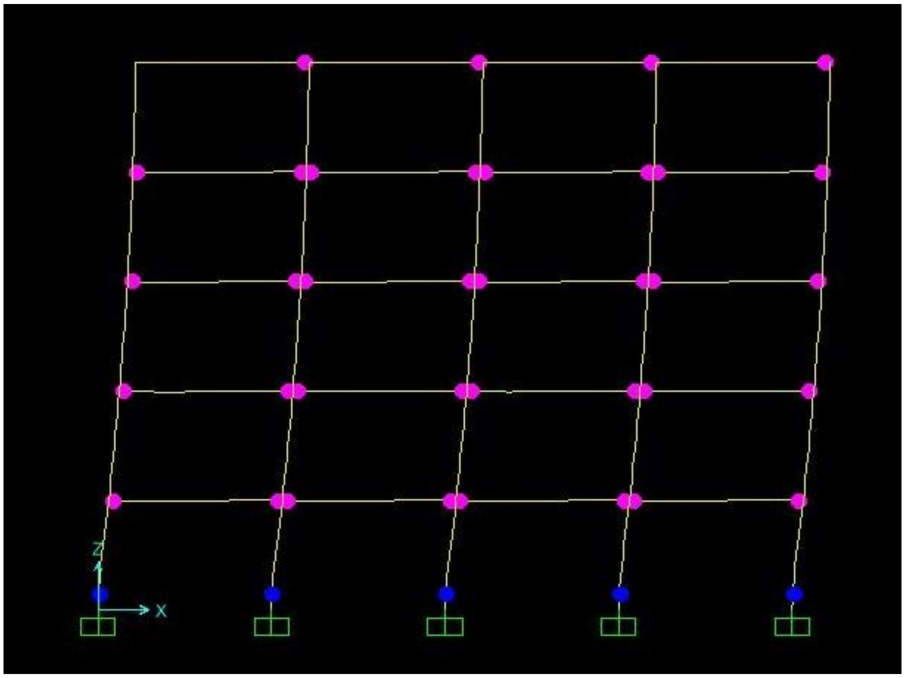


Fig 5.8 Pushover curve for 100 kg TNT

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