ANALYSIS OF BLAST LOAD ON STRUCTURE USING SAP2000

A

PROJECT REPORT

Submitted in partial fulfillment of the requirement for the award of the degree

of

BACHELOR OF TECHNOLOGY

IN

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Under the supervision

of

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

May- 2019

STUDENT'S DECLARATION

I hereby declare that the work presented in the Project report entitled **"Analysis of blast load on structure using SAP2000 "** submitted for partial fulfillment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Mr. Kaushal Kumar**. This work has not been submitted elsewhere for the reward of any other degree/diploma. I am wholly responsible for the contents of my project report.

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Date : May, 2019

CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"Analysis of blast load on structure using SAP2000"** in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Shivani Negi and Ashutosh Sharma** during a period from August, 2018 to May, 2019 under the supervision of

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The above statement made is correct to the best of our knowledge.

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ABSTRACT

A bomb blast inside or quickly close-by a structure can cause disastrous harm on the structure's outside and interior auxiliary casings, falling of dividers, smothering of extensive fields of windows, and closing down of basic life-wellbeing frameworks. Death toll and wounds to inhabitants can result from numerous causes, including direct impact impacts, auxiliary breakdown, flotsam and jetsam effect, flame, and smoke. The circuitous impacts can consolidate to repress or counteract auspicious departure, along these lines adding to extra setbacks.

Furthermore, significant disasters coming about because of gas-substance blasts result in extensive powerful loads, more noteworthy than the first plan loads, of numerous structures. Because of the risk from such extraordinary stacking conditions, endeavors have been made amid the previous three decades to create strategies for basic examination and configuration to oppose impact loads. Studies were directed on the conduct of basic cement exposed to impact loads. These examinations step by step upgraded the comprehension of the job that auxiliary subtleties play in influencing the conduct.

The steel structure and concrete structure subjected to blast loads was examined and then the results were compared. The software SAP 2000 was used to model the structures with different boundary conditions. For the load calculation, Kinney Graham approach was used to determine peak reflected pressure. Further, with time, pressure was applied and time history response was obtained for steel structure and concrete structure.

Keywords: Blast, SAP2000, Dynamic response, Time History analysis, Standoff distance, TNT

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CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION

A blast is a special type of destructive shock ripple resulting in propagation of huge amount of energy in very small interval of time. These waves can harm the structure results in collapsing of walls, loss of lives, injuries to common people due to straight effect of blast, fire and smoke result in destruction of structure. Famous Buildings, Monuments, bridges, oil and gas plant, dams etc. are the framework vital for the economy and prosperity of the country and should be shielded from these destructive blast waves.

It is cleared from the past and present scenario that the number of blast attack has been increased also a number of explosions takes place at oil and gas plants. Past incident have shown that many deaths and injuries were caused by the collapse of building due to blast attack. Also on 1st December, 2016 a huge fire explosion at one of the biggest oil refineries in Italy, in the south of Milan which create serious consequences to public health. Another explosion occurred on the deep water Horizon in the gulf of Mexico To insure safety of blast proof structures against blast events, we should design the structures such that it will minimize the blast effect and ensure the safety for the people inside the structure.

With the growth in technology of civil engineering we can analyses the given structure under dynamic loading such as earthquake loading, wind loading, blast loading etc. Various software's available in the market such as ABACUS, SAP 200, ANSYS, LS DYNA etc. With the help of these software's we will able to find the deformation shape of structure, displacement and forces in different members of structure under the dynamic loading. Also we will able to know whether the structure is capable of bearing particular amount of dynamic load or not.

1.2 GENERAL DEFINITION

1.2.1 DYNAMIC LOADING

A load which varies its magnitude and direction with respect to time. Moving loads such as vehicles on bridges comes under the dynamic loading. Dynamic load such as earthquake load, blast load change rapidly and their magnitude can be greatly increased by its dynamic effect. They are exceptionally dangerous if ignored.

1.2.2. BLAST WAVE

Blast wave is a shock ripple that results due to explosion. Unlike ordinary wave these waves caries huge amount of energy and propagate through medium (solid, fluid or plasma). In the absence of medium these waves travel through an electromagnetic field. Across these waves there is rapid change in pressure and temperature across the flow.

1.2.3. EXPLOSION

Explosion results in release of huge amount of energy in a speedy manner. Due to explosion surrounding temperature and pressure increases rapidly. Explosion is associated with its explosive force, velocity and evolution of heat. It doesn’t require any medium to travel. The direction of explosive force is 90 degree to the explosive surface. Explosion can be natural such as explosion of volcanic eruptions, hydrothermal explosions etc. Explosion take place in universe in the form of supernova is also an example of natural explosion.

Explosions can be chemical, electrical, magnetic and nuclear. These explosions effect the environment adversely and cause permanent injuries and can cause loss of hearing in these disasters.

The different types of burst are:

a. Air burst: Explosive device which uses air as a medium to detonate is known as air burst. In the air but the energy releases from the explosion is evenly distributed throughout the space and distributed over a wider area. However the value of peak energy is not much high. Nuclear explosion comes under the category of Air burst. Air burst is more dangerous than other burst as there is no material present that can absorb the energy released in the Air burst. It leads to maximum destruction and fallout.

b. Surface burst: Detonation of explosive material on the surface of the target is known as Surface burst. In this type of burst energy releases at much more higher rate and due to the contact with surface it may cause destruction of the surface. Surface explosion of blast comes under the category of surface burst.

c. Underground burst: The explosion of explosive material below the surface of ground is known as underground burst. It can lead to generation of earth shock waves especially the place where detonation takes place. Explosion of blast or nuclear weapon beneath the ground comes under the underground burst. These explosion can change the properties of nearby soil also effects the foundation of the nearby structures.

d. Underwater burst: Burst that takes place below the surface of water is known as underwater burst. Explosion can be chemical or nuclear explosion below the surface of water.

1.2.4. LOAD COMBINATIONS FOR DESIGN

While designing the structure the wind load and earthquake load are taken into consideration. Thermal and shrinkage expansions are neglected. Live load, floor load and wall load are taken as per IS-875-1 1967 depending upon the class of building.

1.2.5. DYNAMIC STRENGTH

Due to dynamic loading, plastic deformation may arise in structural members such as beam column and slab etc. which must be allowed as the permanent displacement affects the functioning of the structure. In the state of high rate of strain, structural elements should create adequate or high strength than in the static loaded elements from the structure. (Strain impacts because of impact loading). Moderate yielding stress of mild, structural carbon, weld steels might be expected to surpass the minimum yield stress by 25% and that of composite steel by 10% .The compressive strength should be more than 25% than that of corresponding static strength. It is essential for the structure to have some dynamic strength to withstand the blast load.

1.2.6. TYPE OF BLAST

Blast doesn’t have any special classification. Blast can be inside the structure, outside the structure or it can detonate on the surface of structure. Blast depends upon the amount of explosive material used, the mode of detonation such as moving vehicle (filled with explosive material) detonates, stationary vehicle detonate, ballasting detonate etc. It also depends upon the distance of explosion from the structure and the height of explosive material from the surface of ground.

1.2.7. DETONATION ENERGY

When decomposition of explosive material such as TNT, PETN and AFNO takes place tremendous amount of energy is released with will propagate nearby through the shock wave. This release of energy is called Detonation energy. Decomposition of these materials depends upon the initial degree of confinement, temperature, and the size of the particles. The products formed after decomposition undergoes rapid expansion unlit the reaction stops. This energy can be determined from the Helmholtz free energy or from enthalpy equations.

1.2.8. PROGRESSIVE COLLAPSE

It is a kind of breakdown that emerges from the spread of nearby damage from component to component which results in the breakdown of the whole structure. Generally progressive collapse takes place due to design mistake, faulty construction and abnormal load events. Loads which we don’t consider in structure analysis come under the category of abnormal loads. Pressure loads, for example, blast, internal gas explosion, extraordinary estimations of natural burdens and wind over pressure. Loads, for example, Aircraft sway, quake, vehicle impact, over-burden because of inhabitant abuse additionally goes under the unusual load. The probability of progressive collapse is very less but if it occurs it can lead to social and economic losses. To tackle this problem proper guidelines are made by Department of defense (DOD) and General

Service Administrative (GSA) in the United States. Alternative Load Path (ALP) method is adopted by both DOD and GSA which is used to protect structure from abnormal loads. ALP is a mode which is intended to see the reaction of the structure after damage of one of its significant load bearing part. In this strategy for the most part center or corner column is expelled and reaction is seen. For planning the new structures ALP technique is extremely valuable to investigate the resistance of structure against the dynamic collapse. ALP is a mode which is designed to see the response of the structure after damage of one of its important load bearing member. In this method generally middle or corner column is removed and response is seen. For designing the new structures ALP method is very useful to analyze the resistance of structure against the progressive collapse. The procedure for the ALP analysis is Linear Statics ((LS) and Nonlinear static (NLS) and Nonlinear Dynamic (NLD). From past decades more number of cases of progressive collapse has been seen. Therefore new buildings of significant importance should be design by considering the progressive collapse.

1.2.9. DIFFERENT LOADS WITH THEIR RESPECTIVE FREQUENCIES

Earthquake load also cause dynamic responses but due to blast load dynamic response is more destructive. Fig1.1 (a) shows the frequency of earthquake load, wind load, mechanical waves and the blat load. From the figure it is shown that blast load has substantially higher intensity than other dynamic load within its frequency range, while its frequency mostly lies between medium to high range. However wind load and earthquake load has high intensity at very low frequency but their intensity is not more than blast wave. Fig1.1(b) shows the path of colliding and reflecting blast wave.

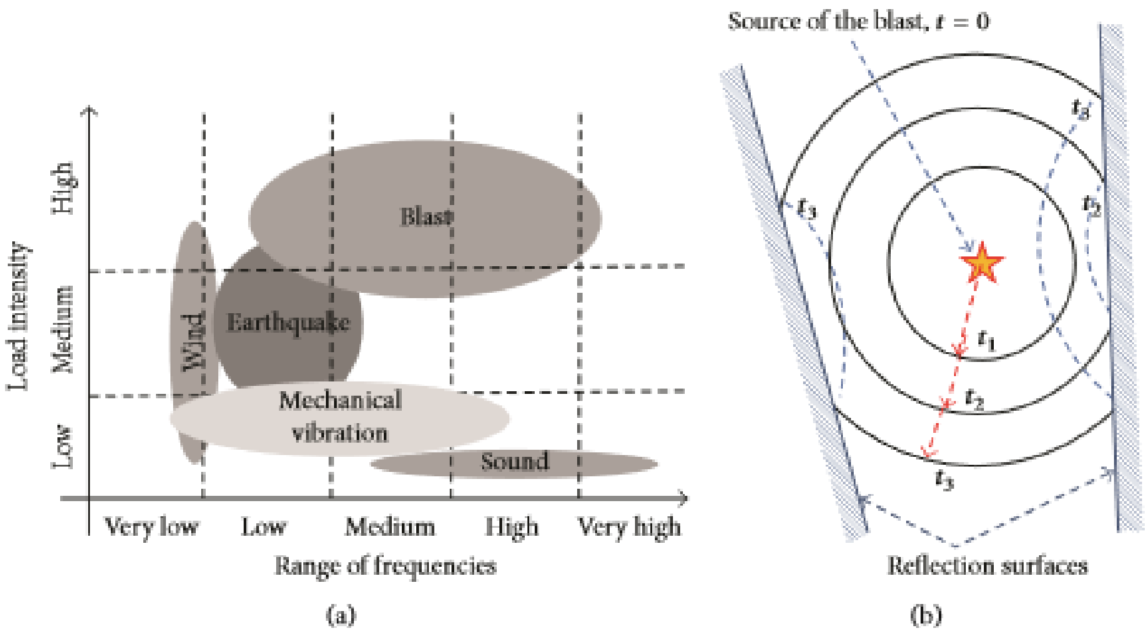


Figure 1.1: (a) Different load with respect to frequency **(b)** Colliding and Reflecting blast wave

[Andreou M. et al 2016]

1.2.10. TYPE OF STRUCTURE WITH RESPECT TO BLAST

These are of two types:

(a) Diffraction type structures: These are the structures that don't have any openings. They have the absolute region which will contradict the blast. The shock wave overpressure and dynamic load brought about by blast wind follows up on such structure.

(b) Drag type structures: These structures have little anticipated region which contradicts the blast wave. Usually dynamic load follows up on such kind of structures.

The discourse in the above area is restricted to surface burst or air burst. It is understood from the above that we can design a structure so that it can oppose the impacts of blast pressure at a specific separation from blast yet it can't be shielded from the surface explosion and from the atomic blast. The enormous activity of atomic weapon is substantially more risky than the ordinary impact.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL:

US department of army, they were the first who study and analysis the blast effects on structure. They released proper guideline manual "Structures to resist the effect of accidental explosion" in 1959. They made the modified release of the manual TM 5-1300(1990) broadly utilized by military and regular citizen association for planning structures to avoid the spread of blast and give assurance to faculty and profitable hardware.

Techniques accessible for forecast of blast wave on structure are:

- Empirical (or analytical) methods
- Semi-Empirical methods
- Numerical methods

Empirical method: The methods which uses the experimental data .The approach by these methods are limited by extend of experimental database. This method uses an empirical equation that diminishes the accuracy of this method as explosive event increases near the field.

Semi-empirical methods: These are based on simplified models of physical phenomenon. This method is dependent on the case study and extensive data. The accuracy of this method is better than the empirical method.

Numerical method: These depend on the arithmetic conditions dependent on the basic law of material science overseeing the issues. They use momentum, law of conservation of energy and mass. Furthermore, the physical conduct of material is portrayed by constitutive relationships. These models are known as Computational fluid dynamics (CFD) models.

The key components are the load produced from explosion source, collaboration with structures and reaction of structure under blast loading. Gas, dust, atomic materials and high explosives are some of hazardous sources. The essential highlights of blast and impact wave marvel are appeared with the assistance of TNT (trinitrotoluene) equivalency and blast scaling laws.

2.2 LITERATURE REVIEW:

J.M. Dewey (1971) studied the blast wave properties got from the trajectories of particle. Out of the blue, he presented the impact of round and hemispherical dynamite (trinitrotoluene) in blast wave. He decided the all through thickness stream utilizing the Lagrangian conservation of mass equation to obtain the pressure by expecting the adiabatic stream for each air component between the shock fronts. Expecting the ideal gas condition of states, density and pressure were resolved from the speed of sound and temperature.

TM 5-1300 (UFC 3-340-02, 1990) manual titled "structures to resist the impact of accidental explosion" give direction to architects well ordered all through the examination and plan system, including the data (i) number of special design consideration (ii) shock loading and blast fragment (iii) reinforced and structural steel design (iv) dynamic analysis principle.

M.V. Dharaneepathy et al. (1995) contemplated the different impacts of stand off distance on tall shells of various heights. He examined the impact of separation (ground-zero separation) of charge on blast reaction. To make a practical expectation of the impact in blast safe design is the basic. The separation among structure and blast is a significant datum which govern the size and span of the blast load. The separation at which blast reaction are most extreme is known as 'critical ground-zero separation', which is utilized as distance for design.

Alexander M. Remennikov (2003) contemplated the distinctive strategies for anticipating bomb blast impacts on structures. At the point when an explosion of high dangerous dynamite produce a blast load on single structure, simplified analytical technique is utilized for acquiring moderate assessments of the blast consequences for structure. For exact forecast of blast load on commercial structures numerical strategies including Lagrangian, Eulerian, Euler-FCT, Lager, and finite element modelling is utilized.

A.Khalid et al. examined the impact of blast load on completely fixed hardened plates to decide the dynamic reaction of the plates with various stiffener arrangements and thought about the impact of mesh density, strain rate sensitivity and time duration. To obtain numerical solution for time integration of the nonlinear conditions of movement central difference method and finite element method were used.

A.K. Pandey et. al. examined the impacts of a blast on the external reinforced concrete shell of a run of the mill atomic control structure. Non-linear material model has been utilized for the analysis till definite stages. To model non-linear analysis into finite element code DYNAIB an analytical procedure has been used.

Kirk A. Marchand et. al. audited the American Institute of Steel construction Inc. for steel structures actualities which give a general study of impact impacts . Number of contextual investigations were produced for damaged building because of blast loading for example Murrah building, Oklahoma City, Khobar Towers, Saudi Arabia, Dhahran and others. He examined the dynamic reaction of steel structure under blast loading and demonstrates the conduct of ductile steel section and associations for blast loads.

Nassar et al (2014) in their paper "Dynamic Response of Steel Column exposed to blast loading" contemplated the conduct of 13 wide – spine steel sections utilizing live Explosive including 50-250 kg of Ammonium nitrate/fuel oil (ANFO) utilizing field tests. The column conveys pivotal burdens equivalent to 25% of their hub load conveying limit. Results demonstrates that, the Axial burden on section may expand the most extreme horizontal removal of the segment because of P-Delta impact and may diminish the sidelong uprooting by the extension of the segment major period. In segments that accomplished plastic deformation, the pivotal burden can expand the most extreme horizontal distortion by up to 158%. The pivotal twisting communication expands the strain rate in the plastic scope of the reaction by upto 93%.

Brian and Halil (2013) in "Experimental and analytical progressive collapse assessment of a steel frame building" explores the progressive collapse capability of a current steel frame working by physically expelling 4-first story segment to comprehend the heap redistribution inside the structure. Field test results are utilized to think about computational models and structures. The 3-D models are more exact than 2-D models as they are maintain a strategic distance from excessively moderate arrangements and lower DCR esteem and vertical relocations. The appeared determined from non-direct powerful examination are littler than the straight static investigation and were shut for measure strains. This papers examine uncovers that it’s better to consider genuine properties promotion associations of the structure to get dependable outcomes.

2.3 SUMMARY OF LITERATURE REVIEW:

- Conduct of structure outlines after the expulsion of a beam or column because of a blast.
- Blast phenomenon and researching the dynamic reaction of a concrete frame structure by using SAP2000.
- The pressure-time history and numerical model of the structure determine the blast load.
- While numerous investigations have concentrated on steel plates presented to confined blast loading, the application is for the most part for aircraft or defensively covered vehicles and isn't identified with basic structure.

2.4 NEED OF STUDY:

- To ensure well being of existing structures against blast occasions, an assessment system for their investigation and possible retrofit is required.
- Specialists have no rules on the most proficient method to plan or assess structures for the blast phenomenon.
- To improve strategies for structural analysis and design to oppose the blast loads.

2.5 OBJECTIVE:

Based on the literature review following objectives are determined:

- To learn the concept of finite element method (FEM) and its implementation on structure.
- To compare the analysis of known results with modeled structure in SAP2000.
- To analyse the effect of blast load on steel structure using SAP2000.

CHAPTER 3

METHODOLOGY

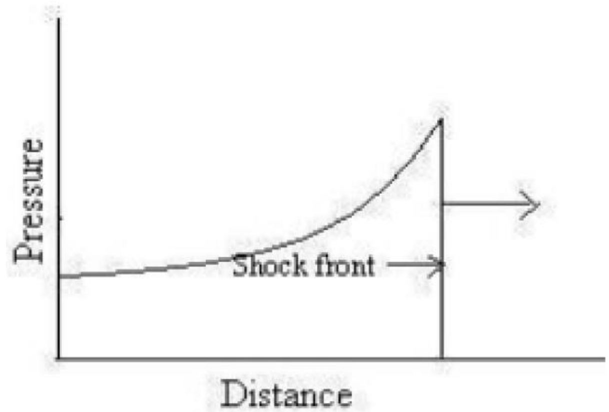
3.1 BLAST PRESSURE CALCULATION

Before progressing towards the calculations of the blast loads the following terms should be considered: (**as per IS 4991:1968**)

1. Stand-off distance – It is the separation between the bomb and building.
2. Blast wind – Due to pressure difference behind the shock wave front, moving air mass along with overpressure is produced. During the positive phase of overpressure the movement of blast wind is in the direction of propagation of the shock front.
3. Clearance time – The time amid which the reflected weight rots descending to the entirety of side on overpressure and drag weight.
4. Drag Force – It is due to blast wind a force acts on a structure. The dynamic pressure is duplicated with the drag coefficient to acquire the drag force on structural component.
5. Decay Parameter – In the pressure time curves the fall of with time is governed by the coefficient of negative power of exponent 'e',i.e. decay parameter.
6. Dynamic Pressure – It is the pressure impact made by the blast wind (for example movement of air mass)
7. Ductility Ratio– It is the proportion of higher deflection to defection of elastic limit.
8. Ground zero – A point on earth surface which is vertically below the explosion.
9. Equivalent bare charge – The weight of an exposed high blast charge is geometrically like any cased charge given creating a similar blast field as the cased charge.
10. Mach number – Proportion of the speed of propagation of shock front to speed of sound in standard environment at sea level.

11. Impulse – The pressure-time obtained from the area under time pressure curve is the impulse per unit of projected area. It is considered for positive phase only until and unless specified.
12. Overpressure – An air blast produces shock wave due to which there is rise in pressure above atmosphere known as overpressure.
13. Side-on overpressure – When overpressure isn't reflected by the surface then it is called side-on overpressure.
14. Reflected overpressure – The overpressure after striking any surface reflects z shock wave front. If the shock front is parallel to the surface then the reflection is considered normal.
15. Shock wave front – It is the intermittence between surrounding atmosphere and bast wave. It engenders at a more prominent speed than the speed of sound in undisturbed air every direction.
16. Yield – It is the proportion of blast measure communicated in equivalent weight of reference explosion.
17. Transit Time – Time required for shock front to traverse the structure.

The pressure wave in the surrounding medium is initiated by unexpected release of energy as appeared in Fig.3.1 (a). After the blast the pressure wave in surrounding air is created due expansion of hot gases. As the pressure wave move far from the center of blast its internal part travels through the regions which was before compacted and later heated by the main part of the wave. This wave goes with the velocity of sound at 3000°-4000°C temperature and about 300 kilo bar pressure of air which cause the increase of velocity. The inward piece of the wave starts to move snappier and relentlessly outperforms the primary piece of the waves. After a concise time frame the blast wave front winds up unforeseen, along these lines surrounding a stun front to some degree like Fig.3.1 (b). The most extraordinary overpressure occurs at the shock front and is known as the peak overpressure. Behind the shock front, the overpressure drops in all regards rapidly to around one-a large portion of the peak overpressure and remains basically uniform in the central region of the impact.



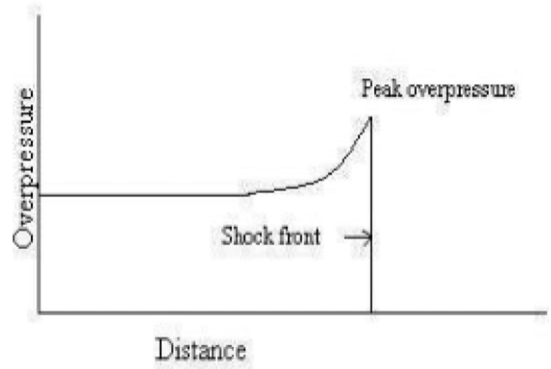


Figure 3.1 (a) Pressure v/s Distance variation **Figure 3.1 (b)** Shock front formation in shock wave

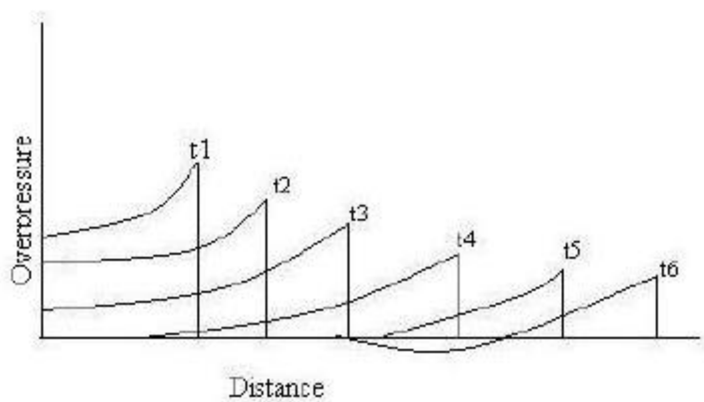


Figure 3.1 (c) Overpressure v/s Distance variation at various time from center of explosion

A development proceeds, the overpressure in the shock front declines tenaciously; pressure behind front does not remain reliable, however rather, tumble off in a conventional manner. Before long, at a particular separation from the center of impact, the pressure behind the shock front reduces than that of the nearby air thus known as negative-phase or suction.

Traditional structures are developed uniquely in contrast to solidified military structures and all things considered are commonly very defenseless against impact and ballistic dangers. So as to configuration structures which can withstand blasts it is important to initially evaluate the impacts of such blasts.

3.1.1 CONVERTING CHARGE MASS INTO EQUIVALENT TNT MASS

For deciding the scaled distance,Z, the source of perspective is use of TNT(Trinitrotoluene). The underlying stage in estimating the blast wave from a source other than the dynamite, is to change over the charge mass into an equal mass of the TNT to be considered. It is performed with the objective that the charge mass of unsteady is increased by the change factor reliant on the specific energy of the charge and TNT. Specific energy of different types of explosives and their change factors to that of TNT are given as:

Table 3.1 Conversion factor for various explosives

Explosion	**Specific Energy** Q_x **KJ/kg**	**TNT Equivalent** $\frac{Q_x}{Q_{TNT}}$
60% Nitro-glycerine (Dynamite)	2710	0.60
RDX (Ciklonit)	5360	1.18
TNT	4520	1.00
Nitro-glycerine(liquid)	6700	1.48
HMX	5680	1.26
Explosive gelatine	4520	1.00
C4	6057	1.34
Semtex	5660	1.25
Compound B (60% RDX, 40% TNT)	5190	1.15

3.1.2 SCALED DISTANCE

All blast parameters basically rely upon the measure of energy discharged by an explosion as a wave impact and the separation from blast. A standardized portrayal of blast effect is given by standoff distance with respect to $\left(\frac{E}{P_O}\right)^{1/3}$ and scaling pressure with respect to P_O, where E is energy released (kJ) and P_O is ambient pressure (usually 100kN/m^2). Generally for the most part the essential input explosive or weight of charge W is expressed as a TNT equivalent.

Results shown are the components of dimensional separation parameter. For explosion and standard charge of substance a parametric relationship is given by scaling laws.

$$\text{Scaled distance } Z = \frac{R}{\sqrt[3]{W}} \tag{3.1}$$

Where,

R- Actual effective distance from the explosion (in m)

W- Charge weight (in kg)

3.1.3 DETERMINATION OF BLAST PRESSURE

a. **PEAK INCIDENT PRESSURE** (P_{s0}) **:** The abrupt expanded estimation of the pressure superficially because of a blast coming about at a division from the surface parallel to the inciting of the impact wave is known as peak incident pressure.

The estimations of peak overpressure because of spherical blast dependent on scaled separation Z was presented by Brode:

$$P_{s0} = \frac{6.7}{Z^3} + 1\ bar\ (P_{s0} > 10\ bar) \tag{3.2}$$

$$P_{s0} = \frac{0.975}{Z} + \frac{1.455}{Z^2} + \frac{5.85}{Z^3} - 0.019\ bar \tag{3.3}$$

$$(10 > P_{s0} > 0.1 bar)$$

Where,

$Z -$ Scaled Distance

$Z = \frac{R}{\sqrt[3]{W}}$

Where,

R – Distance(in m) from center of spherical charge

W – Charge mass(in kg) in terms of TNT

In 1961, Newmark acquainted an association with ascertain the most extreme blast pressure (Pso), in bars, for a high blast charge detonates at the ground surface as:

$$P_{so} = 93\sqrt{\frac{W}{R^a}} + 6.784\,\frac{W}{R^2}\ bar \qquad (3.4)$$

In 1987, Mills presented another surge of the peak overpressure in kPa, in which W is the proportional charge weight in kilograms of TNT and Z is the scaled separation.

$$P_{so} = \frac{108}{Z} - \frac{114}{Z^2} + \frac{1172}{Z^3}\ bar \qquad (3.5)$$

Other than these, Kinney and Graham (1985) based on the analysis of large experimental data introduced the following equation to compute peak positive overpressure.

$$P_{S0} = P_O \frac{808\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\sqrt{\left[\left(1+\left(\frac{Z}{0.048}\right)^2\right)\times\left(1+\left(\frac{Z}{0.32}\right)^2\right)\times\left(1+\left(\frac{Z}{1.35}\right)^2\right)\right]}}\ \text{(bar)} \qquad (3.6)$$

b. **POSITIVE TIME DURATION (t_{pos}):** The time difference between passing of a wave front and the completion of the positive pressure phase set apart by the demise of zero pressure point at a particular surface is called as the positive time duration of the blast wave. The positive time duration of a blast wave on any surface depends on the dissipation of the waves around that surface. If the surface is of small size, the positive time duration will be less as compared to a larger surface as the time required to surpass the surface will be more, hence, less dissipation possible.

Kinney and Graham (1985) presented the following relation for the positive time duration:

$$t_{pos} = W^{1/3} \frac{980\left[1+\left(\frac{Z}{0.45}\right)^{10}\right]}{\left[1+\left(\frac{Z}{0.02}\right)^{3}\times\left[1+\left(\frac{Z}{0.74}\right)^{6}\right]\right]\times\sqrt{\left[1+\left(\frac{Z}{6.9}\right)^{2}\right]}} \text{ (msec)} \tag{3.7}$$

c. **POSITIVE IMPULSE (I_{pos}):** The area which is under the pressure-time history curve is called an impulse. The peak pressure decreases rapidly from the highest value to zero, described as quasi-exponential decrease. For simplicity, this decrease in the value of the peak pressure can be considered as triangular, rectangular keeping the impulse constant.

Kinney and Graham (1985) presented the following relation for positive impulse:

$$I_{pos} = \frac{0.067\sqrt{\left[1+\left(\frac{Z}{0.23}\right)^{4}\right]}}{Z^{2}\sqrt[3]{1+\left(\frac{Z}{1.55}\right)^{2}}} \text{ bar-ms} \tag{3.8}$$

d. **PEAK REFLECTED PRESSURE** (P_{ref})**:** When a pressure wave generated from an explosion impinge a surface at an angle, it is reflected, which results in higher pressure on the surface than the incident side-on pressure. The radial distance of the detonation point from the surface, angle of incidence of blast wave, type of pressure wave, peak incident pressure developed due to explosion and properties of the surface determine the value of reflected pressure. The magnitude of the reflected pressure is generally determined from the coefficient of reflection,

$$P_{ref} = C_r P_{so} \tag{3.9}$$

Where,

C_r= coefficient of reflection

UFC 3-340-02 gives the detailed procedure of determining the peak reflected pressure on a surface depending upon the peak incident pressure and angle of incidence of the waves. Figure shows the coefficient of reflection based on the peak incident pressure of the explosion and the angle of incidence of the blast wave at a particular point on the surface.

The angle of incidence varies from 0° (wave parallel to the surface) to 90° (wave perpendicular to the surface) with the peak incident pressure. A detailed content and charts for anticipating blast pressure and duration were introduced by Mays and Smith and UFC 3-340-02 (2008).

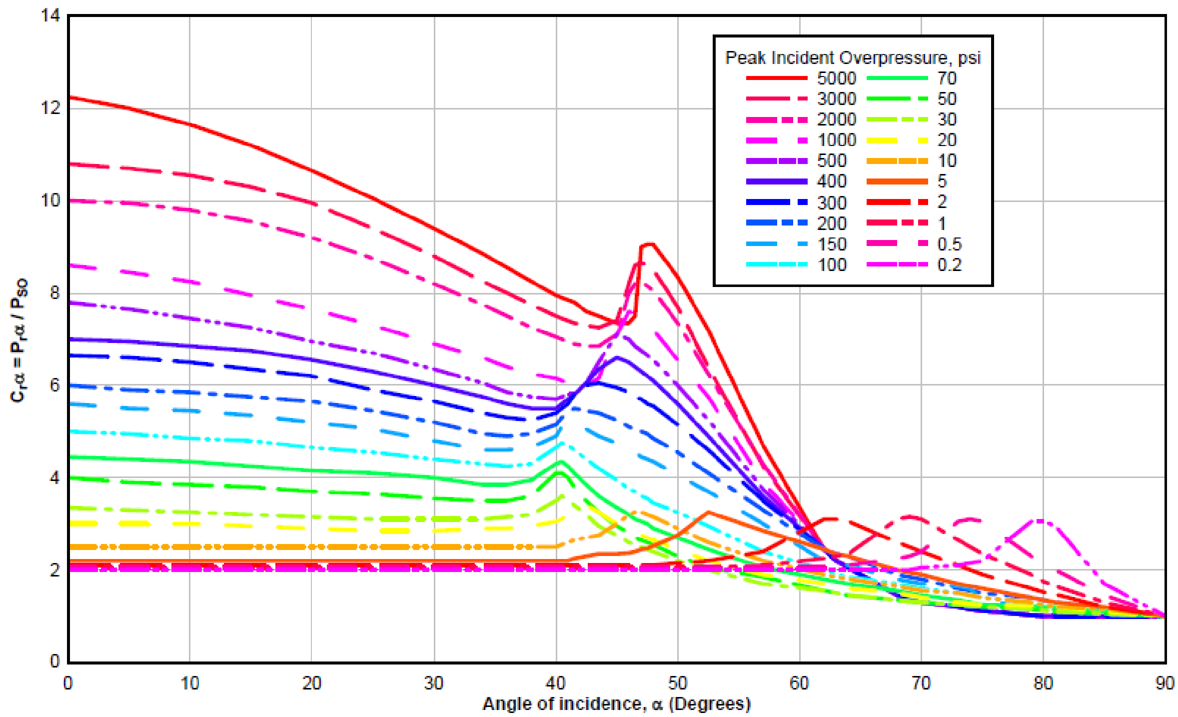


Figure 3.2 Reflected pressure coefficients versus Angle of incidence

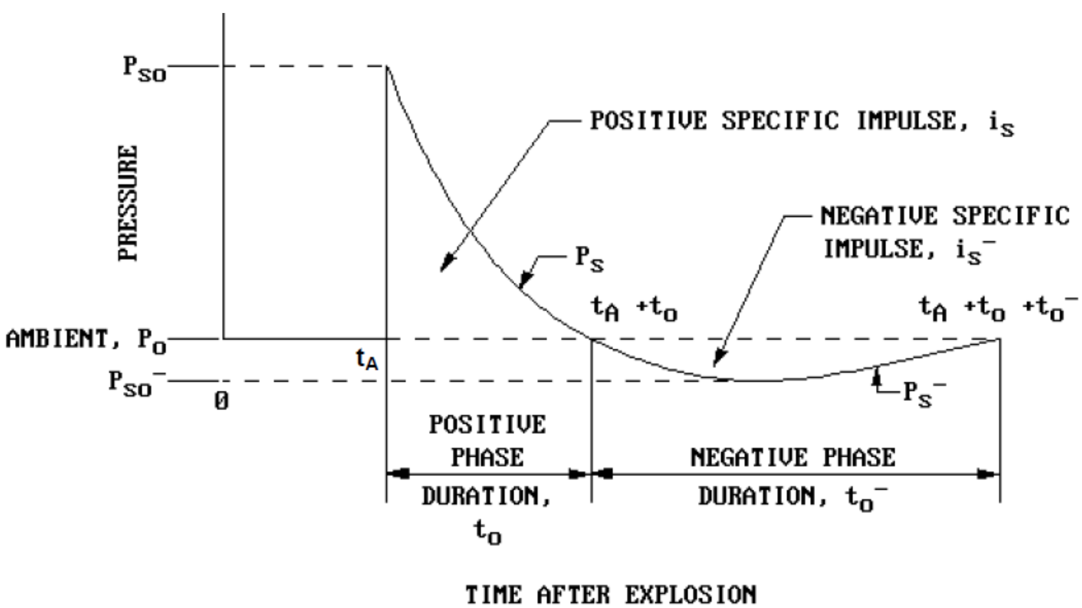


Figure 3.3 Typical Blast Pressure with Time.

Where,

L_w – Length of blast wave

P_{pos} – Static peak pressure

P_r – Reflected peak overpressure

U – Blast wave velocity

i_r – Impact of reflected overpressure

i_s – Impact of static pressure

t_o – Positive phase duration

t_A – Arrival time

For setup purposes, reflected overpressure can be determined by an indistinguishable triangular pulse of greatest peak pressureP_r and time duration t_d and thus yields the reflected impulse(i_r).

$$\text{Reflected Impulse } ((i_r) = \frac{1}{2} P_r t_d \qquad (3.10)$$

Time duration t_d is directly identified with the time taken for the overpressure to be scattered.

Explosive and impact loads similarity to and uniqueness in relation to loads typically used in structure design:

Blast loads and impact loads are decaying with time, or loads that are connected progressively as one-half cycle of high adequacy, brief term air effect or contact and energy exchange similar pulse. This transient burden is connected only for a specific and routinely concise time span by virtue of effect loads, normally less than one-tenth of the second. This infers an additional course of action of dynamic properties not commonly considered by the architect, for instance, rate subordinate material properties and inertial effects must be considered in plan.

Consistently, structure to resist impact, blast and other load must be thought of regarding lifesafety, not to the degree functionality or life-cycle execution. Execution criteria for other basic working environments (atomic reactors, hazardous and influence test workplaces, and so forth.) may require usefulness and reuse, yet most industrial workplace and business work environments won't need to perform to these estimations. Structures expected to repudiate the impact of explosion and effects are allowed to contribute the greater part of their obstruction, the two materials direct and non-straight (inelastic and elastic), to hold harm locally, thus as to not bargain the steadfastness of the whole structure. Almost certainly, local failure can and might be intended to happen, because of the vulnerability related with the loads.

3.2 SEISMIC AND BLAST EFFECTS ON STRUCTURES

Before any word depicting the differentiation among blast and seismic load it will in general be said that, blast loading is inside and out not quite the same as earthquake loading. The essential complexity is emerging a given structure is stacked. Because of a seismic tremor the structure is subject to ground developments that shake the structure beginning starting from the earliest stage (establishment). Because of a blast made by an air or a surface burst, the structure is stacked by techniques for a pressure wave (shock wave) over some zone. Since a touch of the blast energy is coupled into the ground, the structure is moreover subject to ground developments like a tremor, anyway altogether less outstanding.

A second refinement is the range of stacking (rate of stacking). For tremors, the length of affected developments (shaking) can keep running from seconds to minutes. Additional loadings are made by "delayed repercussions," which are regularly less extraordinary than the underlying shaking. For standard explosives, the range of pressure wave is in the range of milliseconds.

3.3 MATERIAL BEHAVIOR AT HIGH STRAIN RATE

An extremely high strain rates in the range of $10^2 - 10^4 s^{-1}$.is produced by an ordinary blast load. This dynamic mechanical properties of target structures is adjusted by high loading rate and, normal harm mechanism for different auxiliary components. The quality of cement and steel reinforcing bars of strengthened solid structure is affected when exposed to blast can increment fundamentally because of strain rate impacts. Figure 3.8 demonstrates the various loading for estimated range of the normal strain rates.. It clearly seen that standard static strain rate is situated in the range: $10^{-6} - 10^{-5} s^{-1}$, whereas blast pressure ordinarily yield loads related with strain rates in the range: $10^2 - 10^4 s^{-1}$.

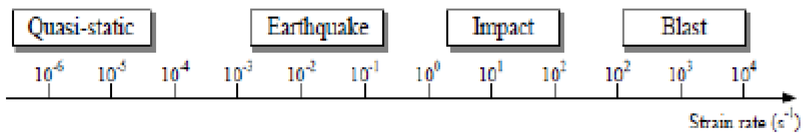


Figure 3.4 Different type of loading with respect to strain rate

CHAPTER 4

COMPARISON OF BLAST PRESSURES

4.1 PROBLEM DEFINITION

- G+3 storey structure is considered. 5m each bay in X-direction and 5m each bay in Y-direction.
- Each storey height of 3m and 4m for ground floor. Therefore the dimension of building is 20m in X direction, 15m in Y direction and 13m in Z direction.
- The loads considered is Live load 3kN/m2, Wall load as 14.14kN/m^3.
- Modeling was carried out in SAP 2000.
- The charge considered is 100Kg RDX and calculation of blast-load parameters were based on UFC 3-340-02 manual.
- Calculation of blast load parameter is given below.
- Scaled distance is found by using formula $Z = \frac{R}{\sqrt[3]{W}}$
- For the scaled distance and charge weight the positive phase duration, peak overpressure, positive incident impulse and arrival time is found out using manual. Also the front wall reflected pressure, impulse, loading is found out for positive phase. The pressure found out is converted to point load by dividing the area and applied to the front face of the structure as shown in figure 4.2.

- **Concrete structure:** Using M 30 concrete, E=200 GPa, Poisson's Ratio=0.2

  Beam: 250mmX450mm

  Column: 350mmX450mm

  Slab thickness: 150 mm and

  Wall thickness: 250mm.

- **Steel structure:** Concrete wall or slab and steel frame

  Steel: Using Fe250, E=200 GPa, Poisson's Ratio=0.3

  Columns: W10X49

  Beam: 24x68

  Design Code: IS 800:2007

  Concrete: Using M 30, E=30GPa, Poisson's Ratio=0.22

  Slab thickness: 150mm

  Wall thickness: 250mm

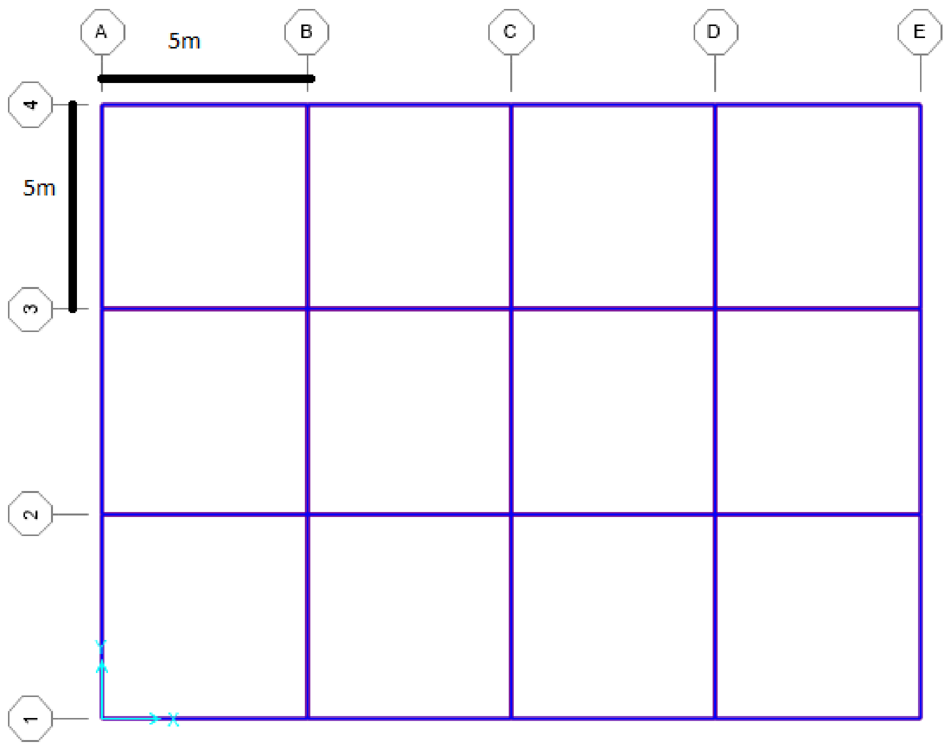


Figure 4.1 X-Y Plan

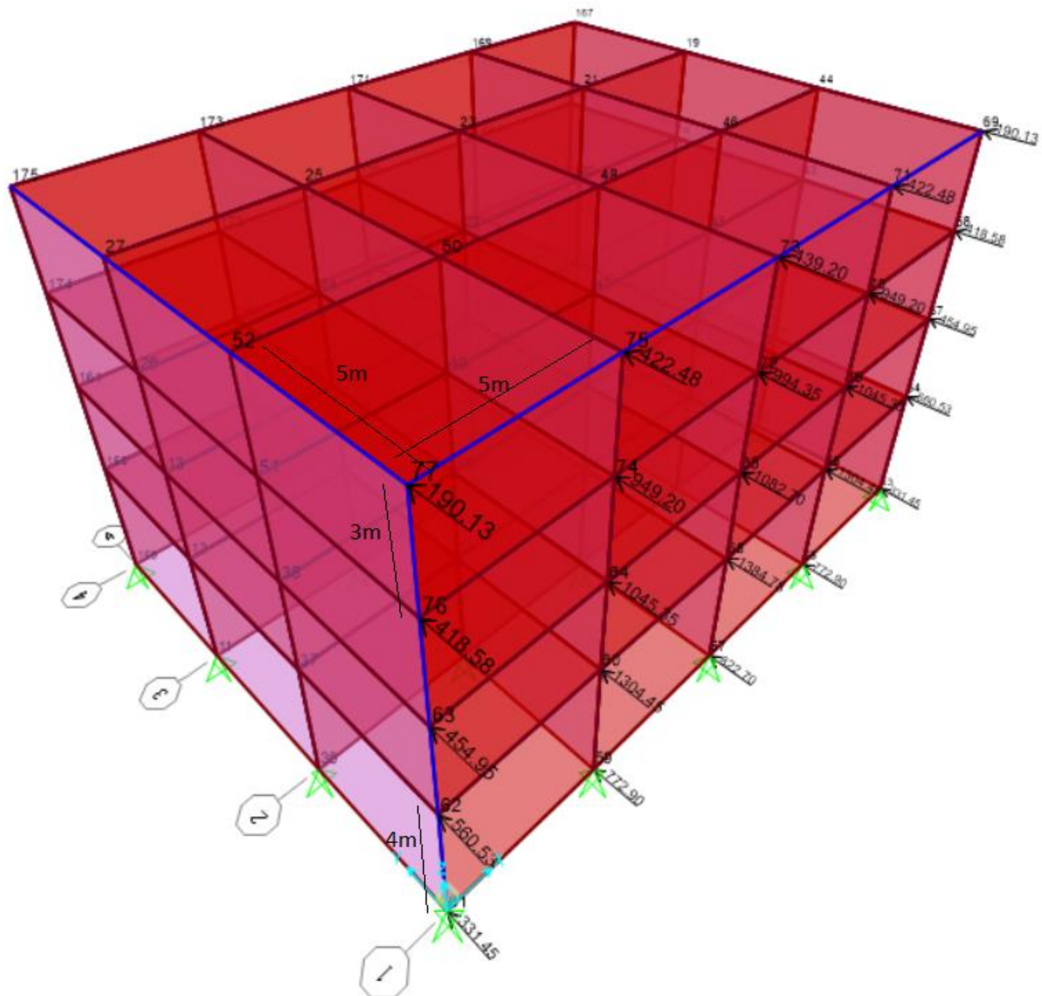


Figure 4.2 3D view of structure used for Modeling

4.2 PEAK REFLECTED PRESSURE CALCULATIONS (KINNEY GRAHAM APPROACH)

The Peak Reflected Pressure is calculated using Kinney and Graham Approach at the grid points. An excel program is made as the various parameters used to calculate pressure can be varied. E.g. Stand-off distance and TNT weight.

For Calculating Peak Reflected Pressure as per Kinney-Graham Approach, following steps are followed:

1. First of all the values of radial distance and angle of incidence at various grid points for various standoff distances is calculated through a program in excel. Various parameters are shown diagrammatically in Fig. 4.2. The calculated data is attached in sheets.
2. After this the values of Peak Incident Pressure, Positive Impulse and positive time
3. Duration is calculated from Kinney-Graham Approach at these grid points.
4. After calculating the value of Peak Incident Pressure and angle at various grid points, the value of coefficient of reflection is interpolated from the graphs in UFC 340-3-2 for various values of Peak Incident Pressure and at various angles. The record of the same is attached below.
5. At last the value of the coefficient of reflection is multiplied with Peak Incident Pressure to get the required Peak Reflected Pressure. The Peak Reflected Pressure is calculated for various Radial Distances at different Standoff Distances and TNT weights. The tubular results are attached herewith.

4.3 PROCEDURE

Following procedure was followed to implement the calculated blast load on the concrete and steel structure.

1. A model is created using grid lines on which beam and columns are drawn as frame and slab or wall are drawn as shell element.
2. Defined materials to the elements, using M30 for concrete and Fe 250 for steel structure.
3. Then defined section properties of beams, columns, slab and wall as given in the problem definition.
4. The load pattern for various joints was defined and then defined the load case for each load.
5. Created load combination for all the load pattern to be assigned.
6. After defining load, calculated blast load using Kinney Graham approach was assigned on the joints of the front face of model.
7. Then assigned the load given in problem definition i.e. live load and wall load.
8. Finally after assigning the loads the model was run and results were analyzed.

Modelling was done for both concrete structure and steel structure. On the basis of analysis comparison of results of both the structures were done to determine the better resistance under blast loading.

4.4 COMPARISON OF CONCRETE STRUCTURE AND STEEL STRUCTURE

a. **DISPLACEMENT:** The displacement of concrete structure is much higher than that of steel structure. For concrete structure the maximum displacement increases as the storey height increases.Whereas for steel structure the maximum displacement remains constant along the storey height.

Table 4.1 Displacement at 10 m standoff distance for concrete structure

STOREY	MAXIMUM DISPLACEMENT CONCRETE STRUCTURE (in m)
BASE LEVEL	0.58
GROUND FLOOR	2
STOREY 1st	4
STOREY 2nd	6
STOREY 3rd	8

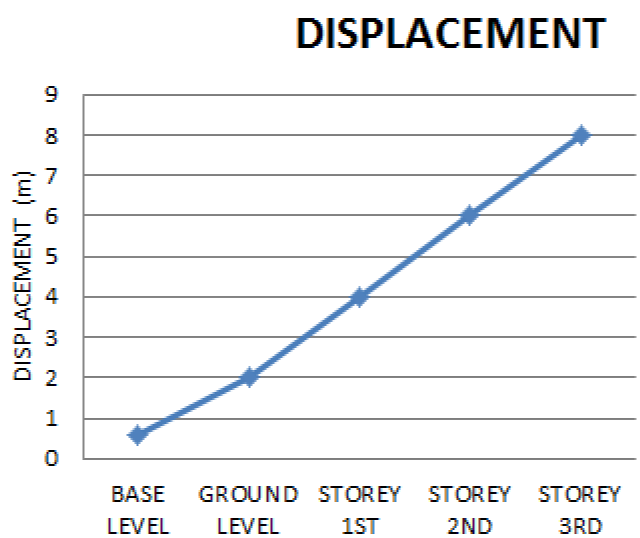


Figure 4.3 Maximum displacement for concrete structure

Table 4.2 Displacement at 10 m standoff distance for steel structure

STOREY	MAXIMUM DISPLACEMENT STEEL STRUCTURE (in m)
BASE LEVEL	0
GROUND FLOOR	0.0001
STOREY 1st	0.0001
STOREY 2nd	0.0001
STOREY 3rd	0.0001

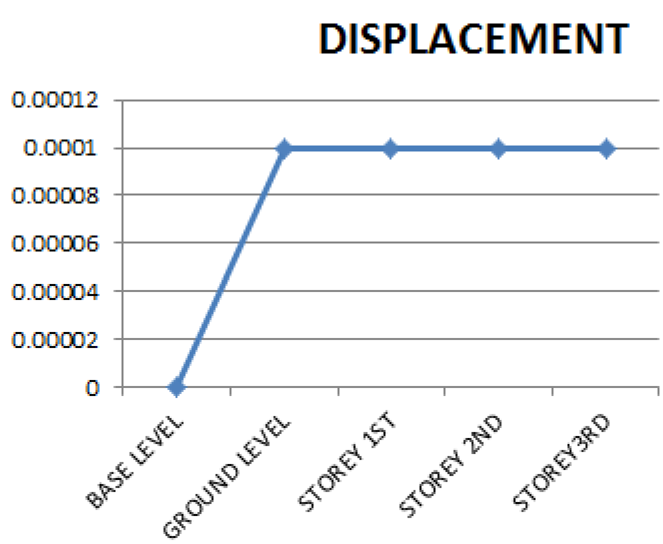


Figure 4.4 Maximum displacement for steel structure

b. SHEAR STRESS: The maximum shear stresses in concrete are more as compared to steel model. In steel model the shear stress decreases with the storey height.

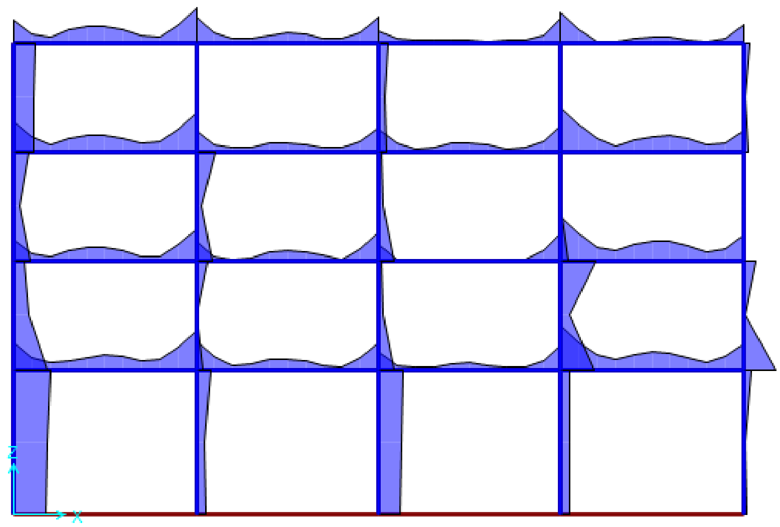


Figure 4.5 Shear stress for concrete structure

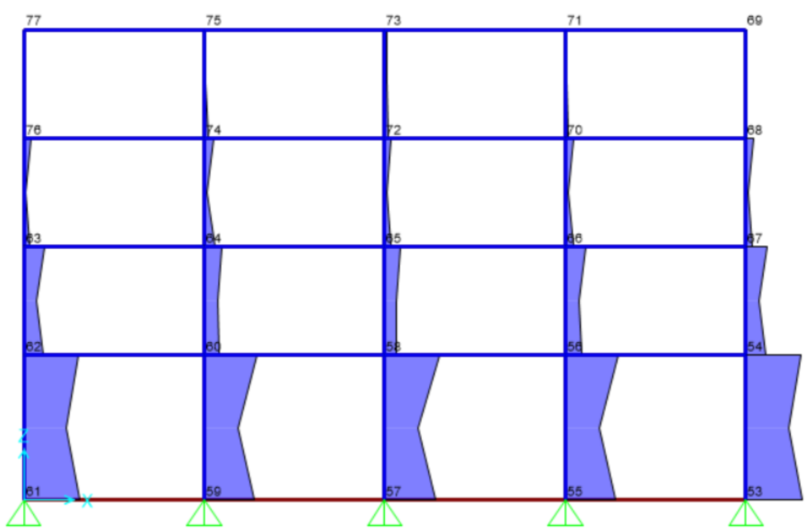


Figure 4.6 Shear stress for steel structure

c. AXIAL FORCE: The axial forces are more in concrete than in steel model and the axial force for steel decreases with storey height.

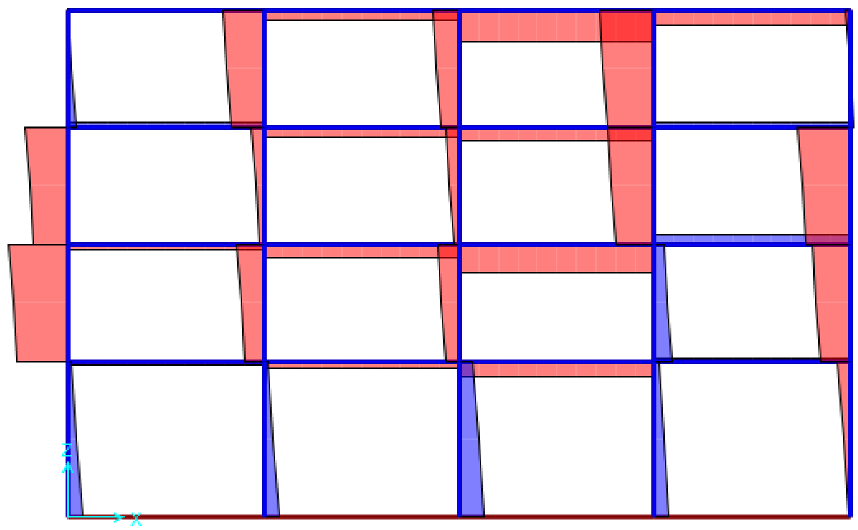


Figure 4.7 Axial force for concrete structure

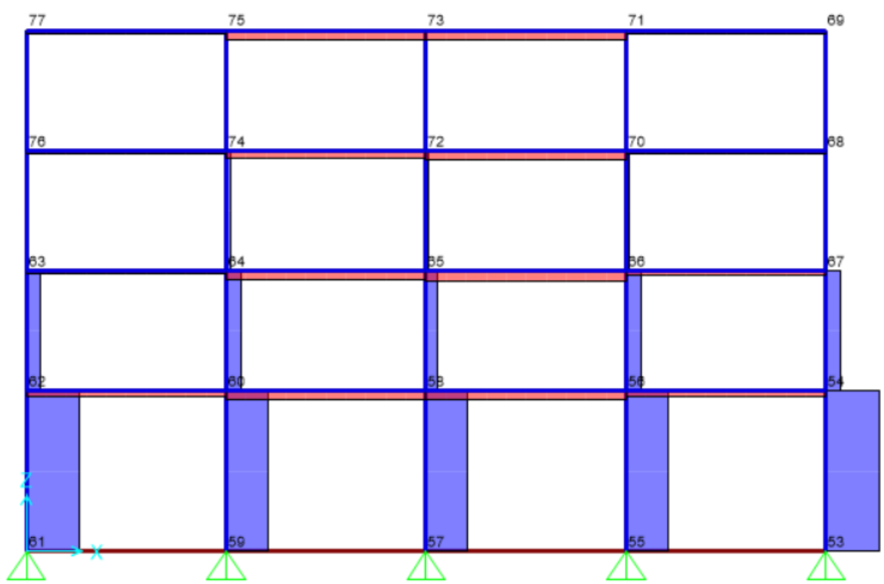


Figure 4.8 Axial forces for steel structure

d. BENDING MOMENT DIAGRAM: The bending moment is more in concrete than in steel model.

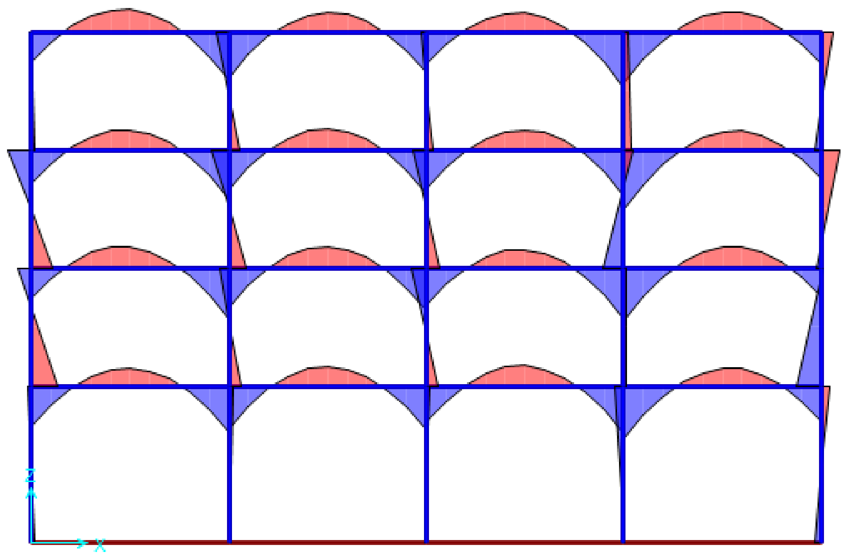


Figure 4.9 Bending Moment for concrete structure

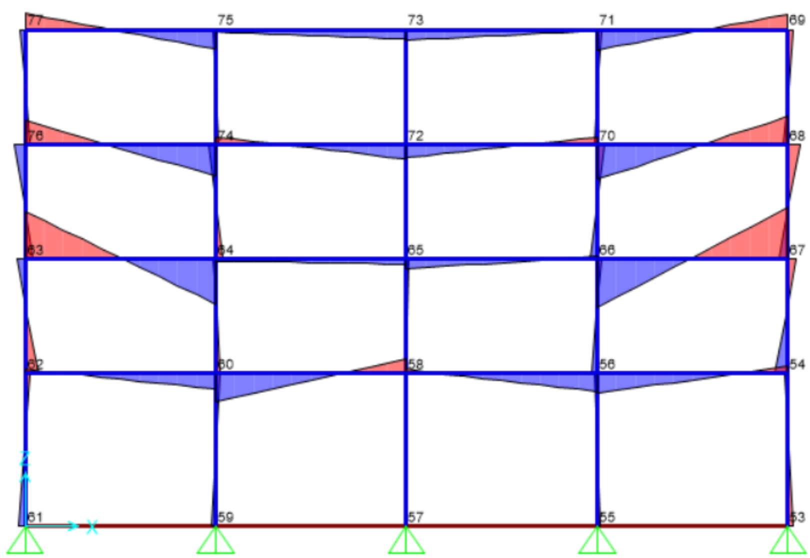


Figure 4.10 Bending Moment for steel structure

CHAPTER-5

TIME HISTORY ANALYSIS

5.1 ANALYSIS

Time history analysis of the section under blast load is analyzed using a program, for example, SAP2000. Analysis of time-history is finished in advance insightful to evoke the dynamic reaction of a structure under determined loads that change with time. A few time-history examination alternatives are accessible in SAP2000: linear or nonlinear; modular or direct integration; and transient or occasional. Both material and geometric nonlinearities can be represented while finishing any of the accessible SAP2000 time-history examinations.

A period history examination utilizing modular superposition utilizes shut structure combination of the modular conditions to figure the structure reaction. Modular superposition expects direct variety of the time capacities between the information focuses. In SAP2000, modular superposition is intended for basic frameworks that are principally straightly versatile, yet have a predetermined number of predefined nonlinear components. Modular superposition is normally more precise and proficient than direct joining, however direct coordination of the conditions of movement can represent all contributing nonlinearities.

A transient investigation has a one-time connected burden, where an intermittent examination considers the heap to rehash inconclusively with all transient reaction damped out.

The investigation that will be finished in SAP2000 in this examination is a direct time-history analysis utilizing modular superposition.

5.2 ASSIGNING OF TIME HISTORY LOAD

For the forces which are dynamic in nature eg. Earthquake, wind load, blast load etc. its became primary concern of civil engineers to do dynamic analysis of the structure. For this we use time history examination in SAP2000 for nonlinear and linear computation of dynamic basic reaction under the pressure condition which can fluctuate as per time indicated function.

5.2.1 ASSIGNING EARTHQUAKE LOAD

For assigning earthquake load we input the file named as ecentro. This file displays the graph between pressure acting on structure Vs time as shown in figure 5.1

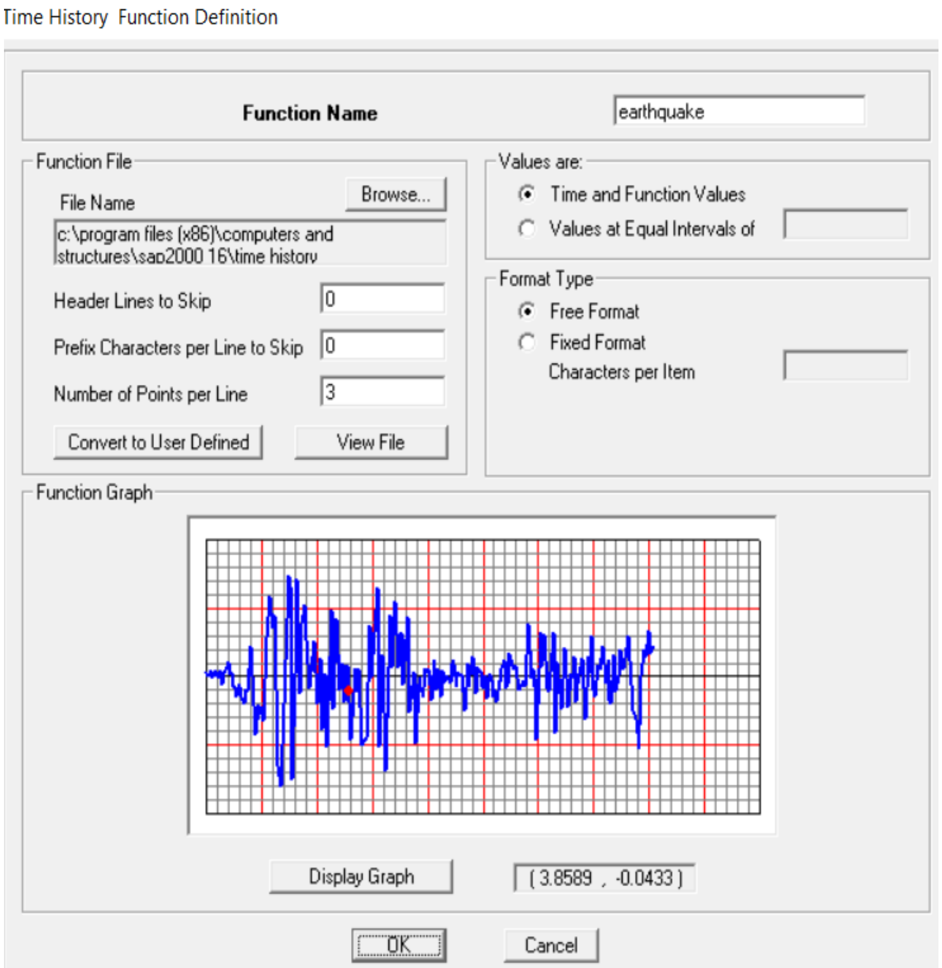


Figure 5.1 Pressure-time history graph for earthquake

5.2.2 ASSIGNING BLAST LOAD

For assigning the blast load firstly we made the graph between pressure on the structure and time. During the blast we calculate the pressure on the structure at different points of time. The Pressure is calculated using Kinney and Graham Approach. Then a graph is plotted between pressure and time and this graph is used as input for the Time History Analysis. Graph between pressure and time is shown in figure 5.2

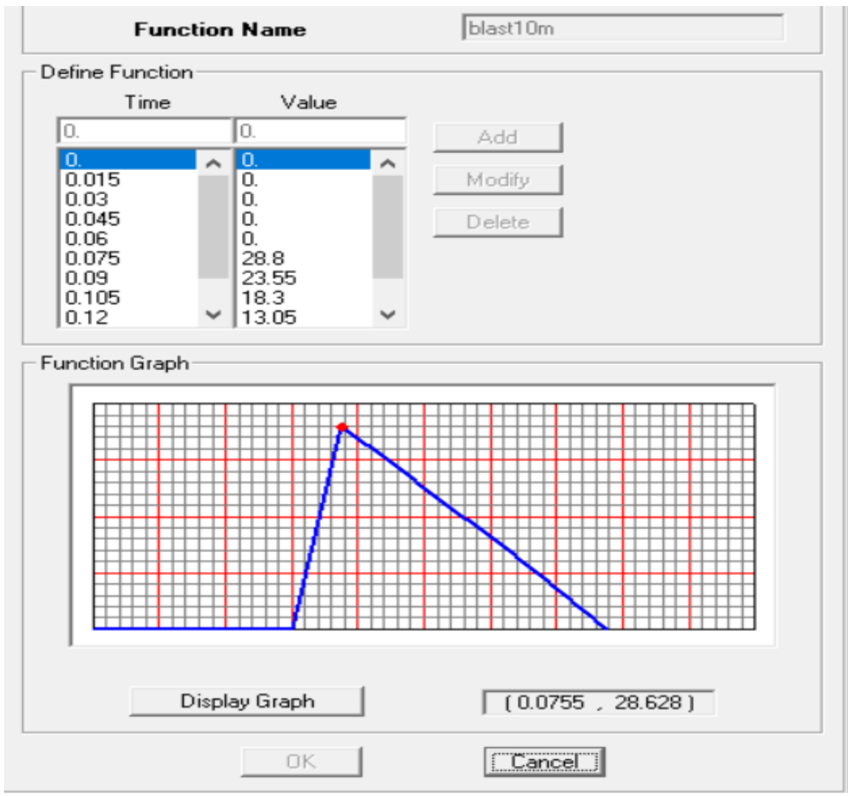


Figure 5.2 Pressure-time history graph for blast load

Table 5.1 Joint reactions for time history analysis and calculated blast load

Joint Reactions	Joint Reaction of Time History Analysis (KN)	Joint Reaction of blast load calculations (KN)
F1	24.78	19.055
F2	26.96	22.11
F3	474.96	465.67

Table gives the maximum displacement for each story using time history method and blast load calculated method (i.e. Kinney Graham approach)

Table 5.2 Displacement of storey using time history and calculated blast load

STOREY	**MAXIMUM DISPLACEMENT**	
	TIME HISTORY (in m)	**BLAST LOAD CALCULATED (in m)**
BASE LEVEL	0	0
GROUND FLOOR	0.0000103	0.000021
STOREY 1st	0.0000080	0.0000099
STOREY 2nd	0.0000042	0.0000056
STOREY 3rd	0.0000024	0.0000038

CHAPTER-6

RESULTS

Table 6.1 gives the different blast loads for different stand-off distances and figure 6.1 shows the variation of blast load as the distance increases.

Table 6.1: Blast Load at different stand-off distance

STANDOFF DISTANCE m	LOAD KN
10	3772.9
20	822.7
30	391.7
40	251.5

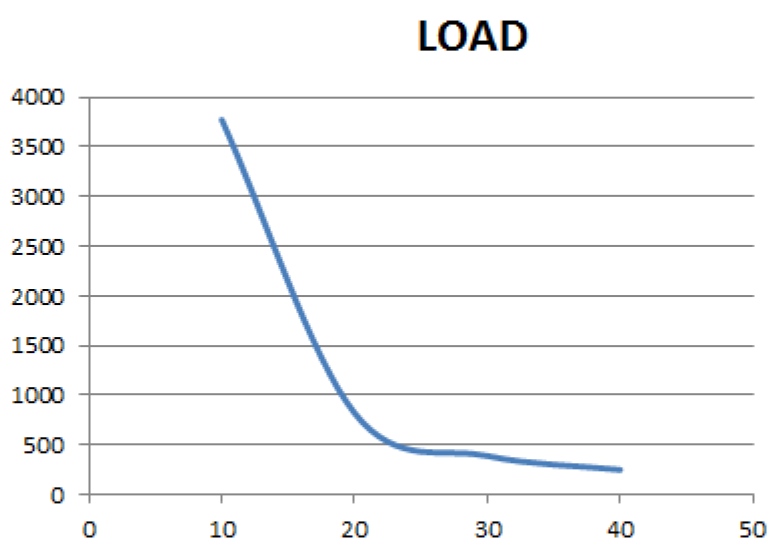


Figure 6.1: Variation of blast load vs stand-off distance

Figure 6.2 depicts the deformation of steel structure due to blast. Blast pressure applied using calculated blast load and pressure-time history analysis. The charge was kept at a stand-off distance of 40m from the base level centre of the front face of model.

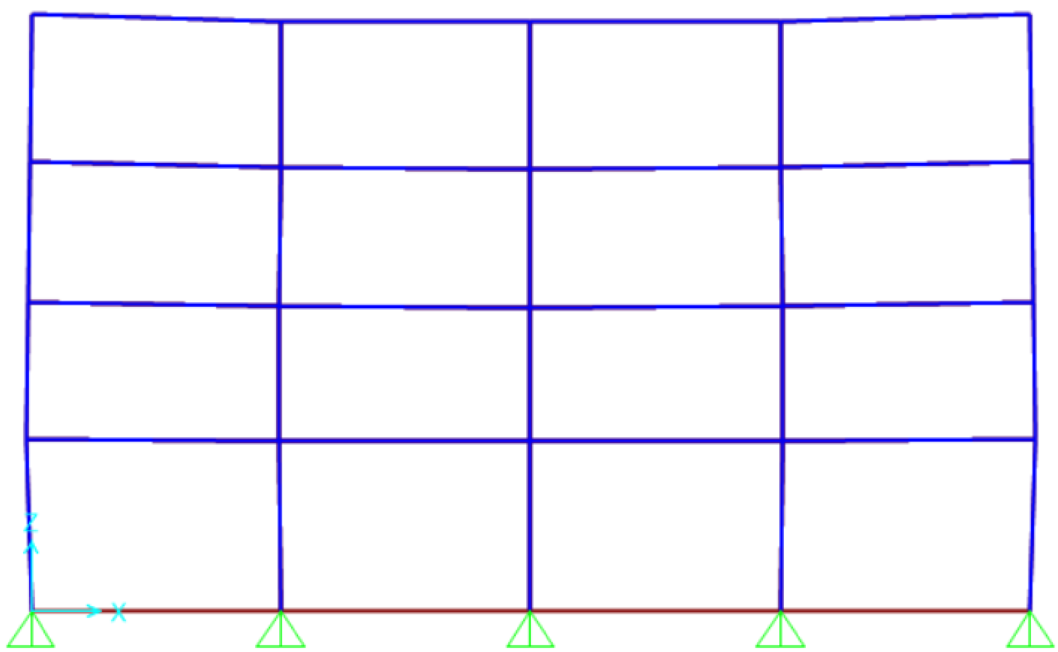


Figure 6.2 Deformation of steel structure at 40m stand-off distance

Figure 6.3 shows the variation of displacement for the two methods used for analysis of steel structure i.e. time history analysis and calculated blasted load. The variation is not much significant.

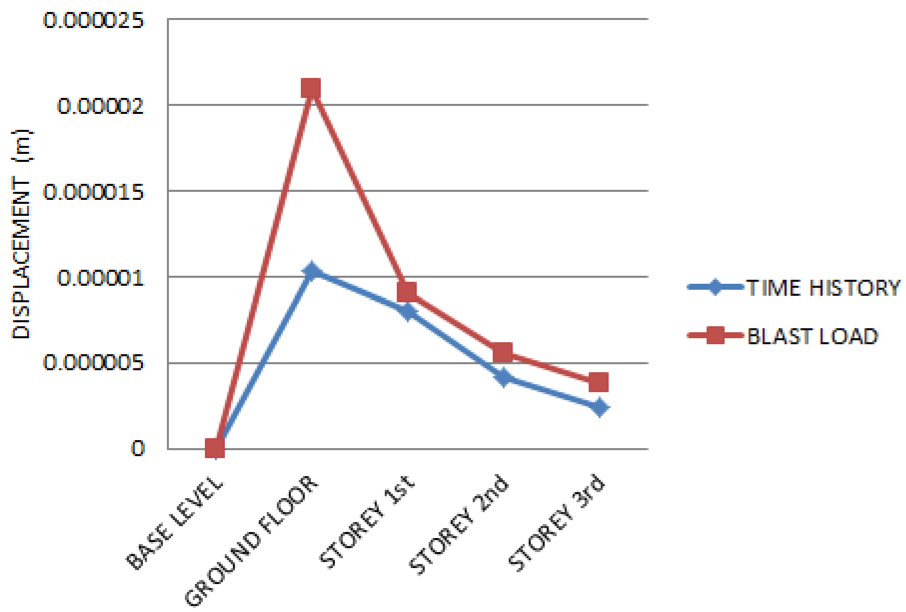


Figure 6.3 Displacement variation for time history analysis and calculated blast load method

CHAPTER-7

CONCLUSION

7.1. CONCLUSION

With the help of literature survey we have calculated the approximate value of blast load or pressure by using kinney and Graham's empirical approach. This method found to be ideal for the calculation of blast load. Due to complex nature of blast it is not easy to get the exact value of blast pressure. We also can't predict the charge weight and setoff distance. Also the behaviour of material under the blast loading is difficult to study.

A G+3 storey steel structure was subjected to blast load under varying standoff distances of 10 m, 20 m, 30m and 40m respectively. The steel model was also compared with the concrete model to determine the better blast resistant material.

The following observations and conclusions can be drawn from the present study.

1. The value of peak reflected pressure as evident from the plots is very high for the radial distance up to 10 m and there is a significant drop (about 2-3 times) in the values of the peak reflected pressure goes from 10 m to 40 m.
2. Also, the values of the peak reflected pressure, for all charge weights, is low for all the radial distances beyond 20 m. Peak reflected pressure increases about 4 times when angle of incidence decreases from 90° to about 0°.
3. On comparing steel model to concrete model, the steel model came out to be a better blast resistant material as the displacement of the steel model was very less as compared to concrete model
4. The variation in results of time history analysis and calculated blast load was not much significant.

7.2 SCOPE OF FURTHER WORK

- Conditions in which the axial load does not stay consistent amid the section reaction time are conceivable. These incorporate circumstances where the bomb is situated inside the structure and the impact energizes the supports associated with the segment. The impact of this time-fluctuating axial load ought to be examined.
- Cases ought to be examined when the blasts inside a structure can cause disappointment of inside braces, bars and floor pieces.
- . Assessment and tests of associations under direct blast loads.

REFERENCES

1. Brian R. I., Sezen, H., (2013). "Experimental and analytical progressive collapse assessment of a steel frame building." *Engineering Structures 56 664–672.*

2. Dewey, M.C., Dewey J.M., (1971), "The properties of the blast waves obtained from the particle trajectories", *Proc. R. Soc. Lond. A.314, pp. 275-299.*

3. Dharaneepathy M. V. (1995), "Critical distance for blast resistance design", *computer and structure Vol. 54, No.4.pp.587-595.*

4. Fang F. (2009)., "Progressive collapse analysis of high-rise building with 3-D finite element modelling method." *Journal of Constructional Steel Research 65- 1269-1278.*

5. Jinkoo. K., Park, J. H., Lee, T. H., (2010). "Sensitivity analysis of steel buildings subjected to column loss." *Engineering Structures 33 421–432.*

6. Khadid M., Zhou, F.,(2006) "The fully fixed stiffened plates under the effect of blast loads", *Journal of Structural Engineering, ASCE.*

7. Mark. C. A., Archilla, J. C., (2006). "A Model for Progressive Collapse of Conventional Framed Buildings." *17th analysis and computation specialty conference.*

8. Mehrdad S., Kazemi, A., Sagiroglu, S., Forest, S. (2011). "Progressive Collapse Resistance of an Actual 11-Story Structure Subjected to Severe Initial Damage." *Journal of Structural Engineering © ASCE, 893.*

9. Nassar, A. A., Razaqpur, A. G., Tait, M. J., Campidelli, M., Foo, S., (2012). "Strength and stability of steel beam columns under blast load." *International Journal of Impact Engineering 55 34e48.*

10. Nassar, A. A., Razaqpur, A. G., Tait, M. J., Campidelli, M., Foo, S., (2014). "Dynamic Response of Steel Columns Subjected to Blast Loading." *ASCE.*

11. Ngo, T., Mendis, P.(2007), "Blast Loads and effects of Blast loads on structures", *EJSE Special Issue: Loading on structures.*

12. Peirs, J., Verleysen, P., Paepegem, W. V., Degrieck, J., (2011). "Determining the stress strain behaviour at large strains from high strain rate tensile and shear experiments." *International Journal of Impact Engineering 38 406e415.*

13. Remennikov M. A., (2003) “A review of methods for predicting bomb blast effects on buildings”, *Journal of battlefield technology, vol 6, no 3. pp 155-161.*
14. Ronald. L. S., (2006), “Response of wide flange steel columns subjected to constant axial load and lateral blast load”. *Civil Engineering Department, Blacksburg, Virginia*.

APPENDIX

Table 9.1 Calculation of Radial Distance and Angle of Incidence for different target points in front face of building for stand-off distance - 10m

S.NO.	Coordinates of point in front of blast at base of the building			Co-ordinates of point vertically above and perpendicular to target ponit			Co-ordinates of target point			Standoff distance S.D.	H	X	Y	R	Alpha	Z
	x1	y1	z1	x2	y2	z2	x'2	y'2	z'2	(metre)	(metre)	(metre)	(metre)	(metre)	(degrees)	
1	0.00	0.00	10.00	0.00	0.00	10.00	0.00	0.00	10.00	10.00	0.00	0.00	0.00	10.00	0.00	2.04
2	0.00	0.00	10.00	0.00	0.00	10.00	5.00	0.00	10.00	10.00	0.00	5.00	5.00	11.18	26.57	2.28
3	0.00	0.00	10.00	0.00	0.00	10.00	10.00	0.00	10.00	10.00	0.00	10.00	10.00	14.14	45.01	2.88
4	0.00	0.00	10.00	0.00	4.00	10.00	0.00	4.00	10.00	10.00	4.00	0.00	4.00	10.77	21.80	2.19
5	0.00	0.00	10.00	0.00	4.00	10.00	5.00	4.00	10.00	10.00	4.00	5.00	6.40	11.87	32.63	2.42
6	0.00	0.00	10.00	0.00	4.00	10.00	10.00	4.00	10.00	10.00	4.00	10.00	10.77	14.70	47.11	2.99
7	0.00	0.00	10.00	0.00	7.50	10.00	0.00	7.50	10.00	10.00	7.50	0.00	7.50	12.50	36.87	2.54
8	0.00	0.00	10.00	0.00	7.00	10.00	5.00	7.00	10.00	10.00	7.00	5.00	8.60	13.19	40.69	2.69
9	0.00	0.00	10.00	0.00	7.00	10.00	10.00	7.00	10.00	10.00	7.00	10.00	12.21	15.78	50.69	3.21
10	0.00	0.00	10.00	0.00	10.00	10.00	0.00	10.00	10.00	10.00	10.00	0.00	10.00	14.14	45.01	2.88
11	0.00	0.00	10.00	0.00	10.00	10.00	5.00	10.00	10.00	10.00	10.00	5.00	11.18	15.00	48.19	3.05
12	0.00	0.00	10.00	0.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	14.14	17.32	54.73	3.53
13	0.00	0.00	10.00	0.00	13.00	10.00	0.00	13.00	10.00	10.00	13.00	0.00	13.00	16.40	52.44	3.34
14	0.00	0.00	10.00	0.00	13.00	10.00	5.00	13.00	10.00	10.00	13.00	5.00	13.93	17.15	54.32	3.49
15	0.00	0.00	10.00	0.00	13.00	10.00	10.00	13.00	10.00	10.00	13.00	10.00	16.40	19.21	58.62	3.91

Table 9.2 Calculation of Radial Distance and Angle of Incidence for different target points in front face of building for stand-off distance - 20m

S.NO.	Coordinates of point in front of blast at base of the building			Co-ordinates of point vertically above and perpendicular to target ponit			Co-ordinates of target point			Standoff distance S.D.	H	X	Y	R	Alpha	Z
	x1	y1	z1	x2	y2	z2	x'2	y'2	z'2	(metre)	(metre)	(metre)	(metre)	(metre)	(degrees)	(metre)
1	0.00	0.00	20.00	0.00	0.00	20.00	0.00	0.00	20.00	20.00	0.00	0.00	0.00	20.00	0.00	4.07
2	0.00	0.00	20.00	0.00	0.00	20.00	5.00	0.00	20.00	20.00	0.00	5.00	5.00	20.62	14.03	4.20
3	0.00	0.00	20.00	0.00	0.00	20.00	10.00	0.00	20.00	20.00	0.00	10.00	10.00	22.36	26.57	4.55
4	0.00	0.00	20.00	0.00	4.00	20.00	0.00	4.00	20.00	20.00	4.00	0.00	4.00	20.40	11.31	4.15
5	0.00	0.00	20.00	0.00	4.00	20.00	5.00	4.00	20.00	20.00	4.00	5.00	6.40	21.00	17.74	4.28
6	0.00	0.00	20.00	0.00	4.00	20.00	10.00	4.00	20.00	20.00	4.00	10.00	10.77	22.72	28.30	4.63
7	0.00	0.00	20.00	0.00	7.50	20.00	0.00	7.50	20.00	20.00	7.50	0.00	7.50	21.36	20.56	4.35
8	0.00	0.00	20.00	0.00	7.00	20.00	5.00	7.00	20.00	20.00	7.00	5.00	8.60	21.77	23.27	4.43
9	0.00	0.00	20.00	0.00	7.00	20.00	10.00	7.00	20.00	20.00	7.00	10.00	12.21	23.43	31.41	4.77
10	0.00	0.00	20.00	0.00	10.00	20.00	0.00	10.00	20.00	20.00	10.00	0.00	10.00	22.36	26.57	4.55
11	0.00	0.00	20.00	0.00	10.00	20.00	5.00	10.00	20.00	20.00	10.00	5.00	11.18	22.91	29.21	4.66
12	0.00	0.00	20.00	0.00	10.00	20.00	10.00	10.00	20.00	20.00	10.00	10.00	14.14	24.49	35.27	4.99
13	0.00	0.00	20.00	0.00	13.00	20.00	0.00	13.00	20.00	20.00	13.00	0.00	13.00	23.85	33.03	4.86
14	0.00	0.00	20.00	0.00	13.00	20.00	5.00	13.00	20.00	20.00	13.00	5.00	13.93	24.37	34.86	4.96
15	0.00	0.00	20.00	0.00	13.00	20.00	10.00	13.00	20.00	20.00	13.00	10.00	16.40	25.86	39.36	5.26

Table 9.3 Calculation of Radial Distance and Angle of Incidence for different target points in front face of building for stand-off distance - 30m

S.NO.	Coordinates of point in front of blast at base of the building			Co-ordinates of point vertically above and perpendicular to target ponit			Co-ordinates of target point			Standoff distance S.D.	H	X	Y	R	Alpha	Z
	x1	y1	z1	x2	y2	z2	x'2	y'2	z'2	(metre)	(metre)	(metre)	(metre)	(metre)	(degrees)	(metre)
1	0	0	30.00	0	0.00	30.00	0.00	0.00	30.00	30.00	0.00	0.00	0.00	30	0	6.11
2	0	0	30.00	0	0.00	30.00	5.00	0.00	30.00	30.00	0.00	5.00	5.00	30.41	9.46	6.19
3	0	0	30.00	0	0.00	30.00	10.00	0.00	30.00	30.00	0.00	10.00	10.00	31.62	18.44	6.44
4	0	0	30.00	0	4.00	30.00	0.00	4.00	30.00	30.00	4.00	0.00	4.00	30.27	7.59	6.16
5	0	0	30.00	0	4.00	30.00	5.00	4.00	30.00	30.00	4.00	5.00	6.40	30.68	12.04	6.25
6	0	0	30.00	0	4.00	30.00	10.00	4.00	30.00	30.00	4.00	10.00	10.77	31.87	19.75	6.49
7	0	0	30.00	0	7.50	30.00	0.00	7.50	30.00	30.00	7.50	0.00	7.50	30.92	14.04	6.3
8	0	0	30.00	0	7.00	30.00	5.00	7.00	30.00	30.00	7.00	5.00	8.60	31.21	15.99	6.35
9	0	0	30.00	0	7.00	30.00	10.00	7.00	30.00	30.00	7.00	10.00	12.21	32.39	22.15	6.59
10	0	0	30.00	0	10.00	30.00	0.00	10.00	30.00	30.00	10.00	0.00	10.00	31.62	18.44	6.44
11	0	0	30.00	0	10.00	30.00	5.00	10.00	30.00	30.00	10.00	5.00	11.18	32.02	20.44	6.52
12	0	0	30.00	0	10.00	30.00	10.00	10.00	30.00	30.00	10.00	10.00	14.14	33.17	25.23	6.75
13	0	0	30.00	0	13.00	30.00	0.00	13.00	30.00	30.00	13.00	0.00	13.00	32.7	23.43	6.66
14	0	0	30.00	0	13.00	30.00	5.00	13.00	30.00	30.00	13.00	5.00	13.93	33.08	24.9	6.73
15	0	0	30.00	0	13.00	30.00	10.00	13.00	30.00	30.00	13.00	10.00	16.40	34.19	28.66	6.96

Table 9.4 Calculation of Radial Distance and Angle of Incidence for different target points in front face of building for stand-off distance - 40m

S.NO.	Coordinates of point in front of blast at base of the building			point vertically above and perpendicular to target ponit			Co-ordinates of target point			Standoff distance S.D.	H	X	Y	R	Alpha	
																Z
	x1	y1	z1	x2	y2	z2	x'2	y'2	z'2	(metre)	(metre)	(metre)	(metre)	(metre)	(degrees)	(metre)
1	0.00	0.00	40.00	0.00	0.00	40.00	0.00	0.00	40.00	40.00	0.00	0.00	0.00	40.00	0.00	8.14
2	0.00	0.00	40.00	0.00	0.00	40.00	5.00	0.00	40.00	40.00	0.00	5.00	5.00	40.31	7.13	8.21
3	0.00	0.00	40.00	0.00	0.00	40.00	10.00	0.00	40.00	40.00	0.00	10.00	10.00	41.23	14.04	8.39
4	0.00	0.00	40.00	0.00	4.00	40.00	0.00	4.00	40.00	40.00	4.00	0.00	4.00	40.20	5.71	8.18
5	0.00	0.00	40.00	0.00	4.00	40.00	5.00	4.00	40.00	40.00	4.00	5.00	6.40	40.51	9.09	8.25
6	0.00	0.00	40.00	0.00	4.00	40.00	10.00	4.00	40.00	40.00	4.00	10.00	10.77	41.42	15.07	8.43
7	0.00	0.00	40.00	0.00	7.50	40.00	0.00	7.50	40.00	40.00	7.50	0.00	7.50	40.70	10.62	8.29
8	0.00	0.00	40.00	0.00	7.00	40.00	5.00	7.00	40.00	40.00	7.00	5.00	8.60	40.91	12.14	8.33
9	0.00	0.00	40.00	0.00	7.00	40.00	10.00	7.00	40.00	40.00	7.00	10.00	12.21	41.82	16.98	8.51
10	0.00	0.00	40.00	0.00	10.00	40.00	0.00	10.00	40.00	40.00	10.00	0.00	10.00	41.23	14.04	8.39
11	0.00	0.00	40.00	0.00	10.00	40.00	5.00	10.00	40.00	40.00	10.00	5.00	11.18	41.53	15.62	8.46
12	0.00	0.00	40.00	0.00	10.00	40.00	10.00	10.00	40.00	40.00	10.00	10.00	14.14	42.43	19.47	8.64
13	0.00	0.00	40.00	0.00	13.00	40.00	0.00	13.00	40.00	40.00	13.00	0.00	13.00	42.06	18.00	8.56
14	0.00	0.00	40.00	0.00	13.00	40.00	5.00	13.00	40.00	40.00	13.00	5.00	13.93	42.36	19.20	8.62
15	0.00	0.00	40.00	0.00	13.00	40.00	10.00	13.00	40.00	40.00	13.00	10.00	16.40	43.23	22.29	8.80

Table 9.5 Peak Reflected Pressure for 118.5 kg TNT Weight & 10 m Stand-off Distance

S.No.	Joint Number (Gauge point)	Radial distance (R) (metre)	Charge Weight (W)(kg)	Scaled Distance (Z) (kg/m3)	Peak Incident Pressure (psi)	Positive Time Duration (ms)	Positive Impulse (Ipos)	Angle of incidence (Degree)	Coefficient of Refraction (Cr)	Peak Reflected Pressure (Pref) (KN/m2)	Area (m2)	Load (KN)
1	57	10.00	118.50	2.04	28.8	80.33	13.14	0.00	1.9	377.29	10	3772.9
2	55	11.18	118.50	2.28	22.24	88.99	12.51	26.57	1.9	291.36	10	2913.6
3	53	14.14	118.50	2.88	13.07	109.35	11.17	45.01	1.9	171.22	5	856.1
4	58	10.77	118.50	2.19	24.42	85.78	12.74	21.80	1.9	319.91	17.5	5598.43
5	56	11.87	118.50	2.42	19.39	93.91	12.17	32.63	1.9	254.02	17.5	4445.35
6	54	14.70	118.50	2.99	12.03	112.89	10.95	47.11	1.9	157.6	8.75	1379
7	65	12.50	118.50	2.54	17.35	98.04	11.89	36.87	1.9	227.29	15	3409.35
8	66	13.19	118.50	2.69	15.24	103.11	11.56	40.69	1.9	199.65	15	2994.75
9	67	15.78	118.50	3.21	10.3	119.77	10.54	50.69	1.9	134.94	7.5	1012.05
10	72	14.14	118.50	2.88	13.07	109.35	11.17	45.01	1.9	171.22	15	2568.3
11	70	15.00	118.50	3.05	11.52	114.79	10.84	48.19	1.9	150.92	15	2263.8
12	68	17.32	118.50	3.53	8.41	129.33	10.01	54.73	1.9	110.18	7.5	826.35
13	73	16.40	118.50	3.34	9.46	123.72	10.32	52.44	1.9	123.93	7.5	929.48
14	71	17.15	118.50	3.49	8.61	128.16	10.07	54.32	1.9	112.8	7.5	846
15	69	19.21	118.50	3.91	6.81	140	9.44	58.62	1.9	89.21	3.75	334.54

Table 9.6 Peak Reflected Pressure for 118.5 kg TNT Weight & 20 m Stand-off Distance

S No.	Joint Number (Gauge point)	Radial distance (R) (metre)	Charge Weight (W)(kg)	Scaled Distance (Z) (kg/m3)	Peak Incident Pressure (psi)	Positive Time Duration (ms)	Positive Impulse (Ipos)	Angle of incidence (Degree)	Coefficient of Refraction (Cr)	Peak Reflected Pressure (Pref) (KN/m2)	Area (m2)	Load (KN)
1	57	20	118.50	4.07	6.28	144.27	9.23	0.00	1.9	82.27	10	822.7
2	55	20.62	118.50	4.20	5.9	147.65	9.06	14.03	1.9	77.29	10	772.9
3	53	22.36	118.50	4.55	5.06	156.33	8.64	26.57	1.9	66.29	5	331.45
4	58	20.4	118.50	4.15	6.04	146.36	9.12	11.31	1.9	79.13	17.5	1384.78
5	56	21	118.50	4.28	5.69	149.69	8.96	17.74	1.9	74.54	17.5	1304.45
6	54	22.72	118.50	4.63	4.89	158.23	8.55	28.30	1.9	64.06	8.75	560.53
7	65	21.36	118.50	4.35	5.51	151.44	8.87	20.56	1.9	72.18	15	1082.7
8	66	21.77	118.50	4.43	5.32	153.42	8.78	23.27	1.9	69.69	15	1045.35
9	67	23.43	118.50	4.77	4.63	161.48	8.4	31.41	1.9	60.66	7.5	454.95
10	72	22.36	118.50	4.55	5.06	156.33	8.64	26.57	1.9	66.29	15	994.35
11	70	22.91	118.50	4.66	4.83	158.94	8.52	29.21	1.9	63.28	15	949.2
12	68	24.49	118.50	4.99	4.26	166.41	8.17	35.27	1.9	55.81	7.5	418.58
13	73	23.85	118.50	4.86	4.47	163.53	8.3	33.03	1.9	58.56	7.5	439.2
14	71	24.37	118.50	4.96	4.3	165.75	8.2	34.86	1.9	56.33	7.5	422.48
15	69	25.86	118.50	5.26	3.87	172.16	7.91	39.36	1.9	50.7	3.75	190.13

Table 9.7 Peak Reflected Pressure for 118.5 kg TNT Weight & 30 m Stand-off Distance

S No.	Joint Number (Gauge point)	Radial distance (R) (metre)	Charge Weight (W)(kg)	Scaled Distance (Z) (kg/m3)	Peak Incident Pressure (psi)	Positive Time Duration (ms)	Positive Impulse (Ipos)	Angle of incidence (Degree)	Coefficient of Refraction (Cr)	Peak Reflected Pressure (Pref) (KN/m2)	Area (m2)	Load (KN)
1	57	30	118.5	6.11	2.99	188.26	7.21	0	1.9	39.17	10	391.7
2	55	30.41	118.5	6.19	2.93	189.63	7.15	9.46	1.9	38.38	10	383.8
3	53	31.62	118.5	6.44	2.75	193.77	6.98	18.44	1.9	36.03	5	180.15
4	58	30.27	118.5	6.16	2.95	189.12	7.17	7.59	1.9	38.65	17.5	676.38
5	56	30.68	118.5	6.25	2.88	190.65	7.11	12.04	1.9	37.73	17.5	660.28
6	54	31.87	118.5	6.49	2.71	194.56	6.94	19.75	1.9	35.5	8.75	310.63
7	65	30.92	118.5	6.3	2.85	191.48	7.07	14.04	1.9	37.34	15	560.1
8	66	31.21	118.5	6.35	2.81	192.3	7.04	15.99	1.9	36.81	15	552.15
9	67	32.39	118.5	6.59	2.65	196.14	6.87	22.15	1.9	34.72	7.5	260.4
10	72	31.62	118.5	6.44	2.75	193.77	6.98	18.44	1.9	36.03	15	540.45
11	70	32.02	118.5	6.52	2.69	195.04	6.92	20.44	1.9	35.24	15	528.6
12	68	33.17	118.5	6.75	2.55	198.59	6.77	25.23	1.9	33.41	7.5	250.58
13	73	32.7	118.5	6.66	2.6	197.22	6.83	23.43	1.9	34.06	7.5	255.45
14	71	33.08	118.5	6.73	2.56	198.28	6.78	24.9	1.9	33.54	7.5	251.55
15	69	34.19	118.5	6.96	2.43	201.67	6.64	28.66	1.9	31.83	3.75	119.36

Table 9.8 Peak Reflected Pressure for 118.5 kg TNT Weight & 40 m Stand-off Distance

S No.	Joint Number (Gauge point)	Radial distance (R) (metre)	Charge Weight (W)(kg)	Scaled Distance (Z) (kg/m3)	Peak Incident Pressure (psi)	Positive Time Duration (ms)	Positive Impulse (Ipos)	Angle of incidence (Degree)	Coefficient of Refraction (Cr)	Reflected Pressure (Pref) (KN/m2)	Area (m2)	Load (KN)
1	57	40	118.5	8.14	1.92	216.63	6.01	0	1.9	25.15	10	251.5
2	55	40.31	118.5	8.21	1.9	217.4	5.98	7.13	1.9	24.89	10	248.9
3	53	41.23	118.5	8.39	1.84	219.33	5.89	14.04	1.9	24.1	5	120.5
4	58	40.2	118.5	8.18	1.91	217.07	5.99	5.71	1.9	25.02	17.5	437.85
5	56	40.51	118.5	8.25	1.89	217.84	5.96	9.09	1.9	24.76	17.5	433.3
6	54	41.42	118.5	8.43	1.83	219.75	5.87	15.07	1.9	23.97	8.75	209.74
7	65	40.7	118.5	8.29	1.87	218.27	5.94	10.62	1.9	24.5	15	367.5
8	66	40.91	118.5	8.33	1.86	218.7	5.92	12.14	1.9	24.37	15	365.55
9	67	41.82	118.5	8.51	1.8	220.58	5.84	16.98	1.9	23.58	7.5	176.85
10	72	41.23	118.5	8.39	1.84	219.33	5.89	14.04	1.9	24.1	15	361.5
11	70	41.53	118.5	8.46	1.82	220.07	5.86	15.62	1.9	23.84	15	357.6
12	68	42.43	118.5	8.64	1.77	221.9	5.78	19.47	1.9	23.19	7.5	173.93
13	73	42.06	118.5	8.56	1.79	221.1	5.82	18	1.9	23.45	7.5	175.88
14	71	42.36	118.5	8.62	1.77	221.7	5.79	19.2	1.9	23.19	7.5	173.93
15	69	43.23	118.5	8.8	1.72	223.48	5.71	22.29	1.9	22.53	3.75	84.49