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BLAST ENGINEERING IN CIVIL INFRASTRUCTURE

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CHAPTER 1

INTRODUCTION

1.1. Background

Military assaults, terrorist attacks and accidental explosion may cause serious damage to buildings and other infrastructures. As a result of terrorist threats and attacks, engineers and transportation office workers are becoming more active in physically protecting bridges from potential blast attacks. Blast incidents can also happen under accidental or intentional circumstances, which are both unpredictable since human behavior is involved. These blast events could cause critical injuries along with heavy casualties in addition to the disastrous structural failure giving rise to detrimental economic and social impacts, both domestically as well as internationally. Unintentional explosions are highly undesirable. In process industries, steps are frequently taken to minimize the causes and consequences of accidental explosions. When explosion occur, attention shifts from prevention to attribution from the perspective of both cause and effect. Taking these concerns into serious consideration structural engineers have paid particular attention in damage effect analyses and assessments of bridge under blast loading.

Blast engineering regarding civil infrastructure has only received rapidly evolving interest in recent years. More researches are being conducted to advance the theoretical and experimental investigation technology, as well as to enhance the level of understanding of the blast implications on multistory buildings, bridges, industrial structures and public facilities. Blast solution which consists of retrofitting options, for existing provisions, design guidelines for future services and preventive measures which aim to hinder blast occurrence and lower blast severity, are under constant development. In recent years, many efforts are made for the development of reliable methods and algorithms for a more realistic analysis of structures and structural components subjected to blast loading. Furthermore with the rapid development of computer hardware over the last decades, it has become possible to make detailed analysis of explosive events in personal computers. Moreover, new developments in integrated computer hydro-codes complete the tools necessary to carry out the numerical analysis successfully. New development in integrated computer hydro-codes or software makes the numerical analysis more convenient[21].

1.2. Purpose and Scope

Conventionally bridge structures were not designed for the blast loads. Since the magnitudes of potential explosive load are significantly higher than other design loads, conventional structures are more susceptible to damage from explosions. Since the 2001 terrorist attacks, numerous researches and demonstrations initiatives have been undertaken to find cost effective techniques and efficient retrofit, security and rapid reconstruction techniques for important buildings. The bridges and highways infrastructures face new challenges relating to the security of critical structures against terrorist attacks. In response to these need, the AASHTO Transportation Security Task Force sponsored the preparation of a guide to assist transportation professionals in identifying critical highway structures and to take action to reduce their blast vulnerability. In order to provide guidance to bridge owners and operators, the Federal Highway Administration (FHWA) formed the Blue Ribbon Panel (BRP) on bridge and tunnel security. AASHTO has probability based design methodology for designing bridges for various dynamic loads such as seismic, ship impact, vehicular collision. However it has no specific guidelines for design of bridges for blast loading. NCHRP has sponsored a research project to develop design and detailing guidelines for blast resistant highway bridges that can be adopted in the AASHTO bridge design specification.[1]

A Blue Ribbon Panel sponsored jointly by the Federal Highway Administration (FHWA) and American Association of State Highway and Transportation Officials, acknowledged that the nation's bridges and tunnels are vulnerable to terrorist attacks. The panel report includes recommendations on actions that can be taken by bridge owner and operator by FHWA, and other state and federal agencies. The American Society of Civil Engineers (ASCE) developed design guidelines entitled "Design of Blast Resistant Buildings in Petrochemical Facilities." This report provides general guidelines for structural design of blast resistant petrochemical facilities.[3]

Bridges are less protected as compared to other structures such as high rise buildings, federal and state offices, and other important structures. Loads imposed on the highway bridge components during a blast loading event can exceed those for which bridge components are currently being designed. In some cases, the loads can be in the opposite direction of the conventional design loads. Consequently, highway bridges designed using current design codes may suffer severe damages even from a relatively small sizes explosion. For example, Figure 1.1 shows a bridge in Iraq severely damaged by a relatively small amount of explosive placed by terrorists near piers of the bridge.

Figure1.1.A bridge in Iraq damaged by a relatively small amount of explosives placed in a terrorist attack [3].

The highway department categories damages bridge structures as partially or completely out of service based on the location, extent and intensity of damage. It was assumed that bridge might collapse due to the individual failure of one or more structural members including deck, beam, pier or column. Bridge columns are more vulnerable to blast attacks because of their easy access and more likely to be attacked due to their importance in structural stability. Therefore they are considered the most critical element of a bridge structure in terms of failure and stability. Columns are more accessible and susceptible to damage in case of a ground-based or water-borne blast attacks. The deck slab and girder of a bridge is also highly vulnerable to blast attack because of its close proximity to moving vehicles. The deck is susceptible to damage in case of an explosion originating under the bridge as compared to an over the bridge explosion. The girder plays an important role in securing the superstructure and substructure by creating redundancy against sudden collapse. Girders are typically designed to withstand moments and shears caused by vertically downward loads. On the other hand, a vertically upward load, caused by blast load from underneath the bridge will cause negative moments and shear. Thus, loads imposed on highway bridge components during a blast loading event can exceed the design capacity of those members. In some cases the loads can be in the direction opposite to those of conventional design loads. Consequently, highway bridges designed using current design codes may suffer severe damage even from a relatively small size explosion. Although several guidelines for the design of blast resistant buildings exist, e.g., U.S. Dept. of Defense Army (USDOA) (Baker et al. 1992), U.S. Dept. of Defense (USDOD) (2002, 2008), Defense Threat Reduction Agency (DTRA) (1997), U.S. General Services Administration (GSA) (2003), Interagency Security Committee (ISC) (2001), National Institute of Standards and Technology (2007), and ASCE (2010), there is very limited information available on analysis, design, and detailing of bridge components subjected to blast loads[3].

1.3. Blast Phenomenon

An explosion is the result of a very rapid release of large amounts of energy within a limited space. Explosions can be categorized on the basis of their nature as physical, nuclear and chemical events.

In physical explosion: - Energy may be released from the catastrophic failure of a cylinder of a compressed gas, volcanic eruption or even mixing of two liquid at different temperature.

In nuclear explosion: - Energy is released from the formation of different atomic nuclei by their distribution of the protons and neutrons within the inner acting nuclei.

In chemical explosion: - The rapid oxidation of the fuel elements (carbon and hydrogen atoms) is the main source of energy.

The type of burst mainly classified as,

- Air burst
- High altitude burst
- Under water burst
- Underground burst
- Surface burst

The destructive action of nuclear weapon is much more severe than that of a conventional weapon and is due to blast or shock. The sudden release of energy initiates a pressure wave in the surrounding medium, known as a shock wave as shown in Figure.1.3. When an explosion takes place, the expansion of the hot gases produces a pressure wave in the surrounding air. As this wave moves away from the centre of explosion, the inner part moves through the region that was previously compressed and is now heated by the leading part of the wave. As the pressure waves moves with the velocity of sound, the temperature is about 3000^{o}-4000^{o}C and the pressure is nearly 300 kilo-bar of the air causing this velocity to increase. The inner part of the wave starts to move faster and gradually overtakes the leading part of the waves. After a short period of time the pressure wave front becomes abrupt, thus forming a shock front somewhat similar to Figure.1.3. The maximum overpressure occurs at the shock front and is called the peak overpressure. Behind the shock front, the overpressure drops very rapidly to about one-half the peak overpressure and remains almost uniform in the central region of the explosion. An expansion proceeds, the overpressure in the shock front decreases steadily; the pressure behind the front does not remain constant, but instead, fall off in a regular manner. After a short time, at a certain distance from the centre of explosion, the pressure behind the shock front becomes smaller than that of the surrounding atmosphere and so called negative-phase or suction. The front of the blast waves weakens as it progresses outward, and its velocity drops towards the velocity of the sound in the undisturbed atmosphere. This sequence of events is shown in Figure.1.3.[10]

Figure.1.2.Variation of pressure with distance[10]. Figure.1.3.Formation of shock front[10].

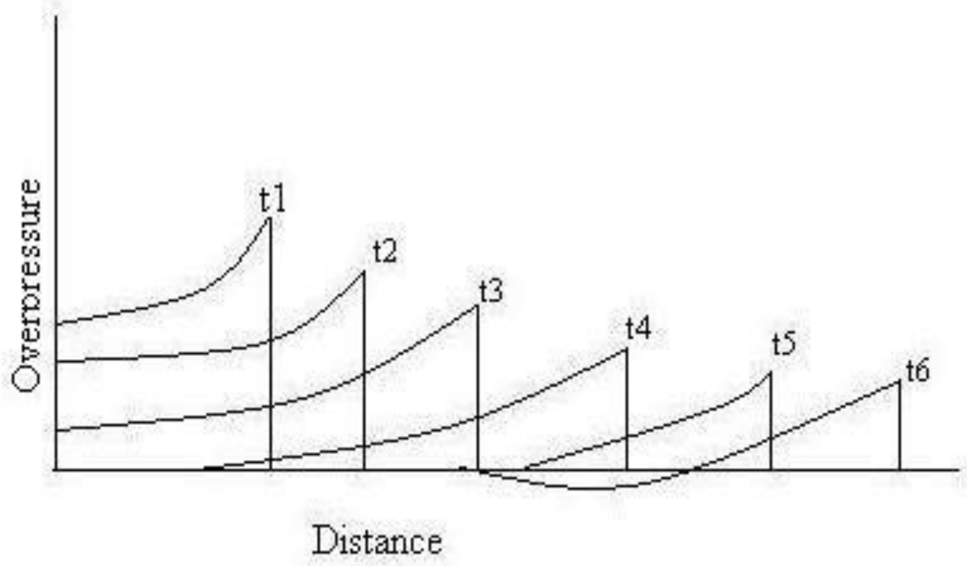


Figure.1.4. Variation of overpressure with distance[10].

1.4. Introduction to Explosive

Blast is an energy distribution process in which a large amount of energy disperses in a very, very short time. The time duration for blast/shock environments of interest are typically in the range of .5 to 1.0 m-s with loadings in the range of several thousands of pounds per square inch. Although there are different forms of explosive threats major explosive threat to highway bridges may be caused by high explosive bombs (e.g., general purpose bombs which cause damage by blast and fragmentation and light case bombs which primarily produce blast damage), vehicle bombs and incendiary bombs (in which blast effects are augmented by a fireball from a burning fuel such as fuel). When a building is designed to resist blast loads, lethal fragmentation of glass or concrete is a very important factor because of its potential to cause injury and death to occupants. This is less important for blast-resistant design of bridges. Hence assumptions are made that the structure is damaged by high explosive blast wave load without piercing or fragmenting effects. When a bridge deck is subjected to explosive loads or missile attacks, it is possible that the explosive may cause local damage in the deck. The bridge may not collapse in such situations and can still sustain the traffic. Figure 1.5 shows a bridge in Palestine after a missile attack.

Figure.1.5. Damage to a Bridge in Palestine after a Missile Attack[3].

1.4.1. Nature of Explosion

Explosive materials are designed to release large amounts of energy in a short time. The explosion arises through the reaction of solid or liquid chemicals or vapor to form more stable products, primarily in the form of gases. A high explosive is one in which the speed of reaction (typically 5,000-8,000 m/s) is faster than the speed of sound in the explosive. High explosives produce a shock wave along with gas, and the characteristic duration of a high-explosive detonation is measured in microseconds (10^{-6}s). Explosives come in various forms, commonly called by names such as TNT, PETN, RDX. The effects of explosions on structures are directly related to stress-wave propagation as well as impact and missile penetration. In all close-in explosions, where shock waves must travel through the surrounding medium to cause damage to a facility, a realistic description of the wave-propagation phenomena is needed.

1.4.2. Effects of explosives

If a detonating explosive is in contact with a solid material, the arrival of the detonation wave at the surface of the explosive will generate intense stress waves in the material, producing crushing and shattering disintegration of the material. This hammer-blow effect is called 'brisance'. The dynamic pressure at the detonation wave-front is the detonation pressure p_1 given in kilo-bars by the empirical equation. [3]

$$p_1=2.5\times 10^{-9}\rho D^2 \qquad (1.1)$$

where,

ρ (kg/m3) is explosive density and

D (m/s) is detonation wave speed.

Thus if D is7400 m/s and ρ (kg/m^3) = 1500 kg/$m^3$for RDX, then the detonation pressure p_1 is given by Equation 1.1 is 205.4 kilo-bars, which is far in excess of the compressive strength of most materials.

Below pictures shows the effect of blasts due various kind of events and explosive materials.

Figure 1.6.Alfred P. Murrah Federal Building after Explosion.

Figure 1.7. Oil Tanker Blast at Interstate.

Figure 1.8. Column Damage due to explosion under bridge

1.5. Blast Vulnerability Assessment

Not much work has been done on the blast vulnerability of bridge structures. Naturally, the bridges are less protected as compared to other structures such as high-rise buildings, federal and state offices, and other important structures. The national highway system has been carefully networked with almost 600,000 bridges around the country (NBI 2003). As traffic flow continues over the interstate and state highways 24 hours a day, it is a common perception that the bridges are protected to some extent by the moving traffic. However, there are growing concerns evolving nowadays because of the terrorist attacks at home and abroad. The government has adopted utmost security measures for protecting important bridges in response to the terrorist threats of attacking these bridge structures. On the other hand, regular interstate and highway bridges are not being paid enough attention to secure them against terrorist attack. Therefore, these bridges are more vulnerable to attack, which may cause casualty as well as social and economic losses, and disrupt traffic movement affecting the transportation system and network around the country.

A structure is likely to be subjected to various types of hazards during its life time. These hazards can be subdivided into two general categories: man-made (blast) and natural (earthquakes, wind, etc). For a successful approach to any system design, it is essential to understand the nature of the hazard. Dynamic hazards can be described by their relative amplitudes and relative time (frequency) attributes. Figure 1.9.shows a schematic representation of the amplitude-frequency relationships of several dynamic hazards.[3]

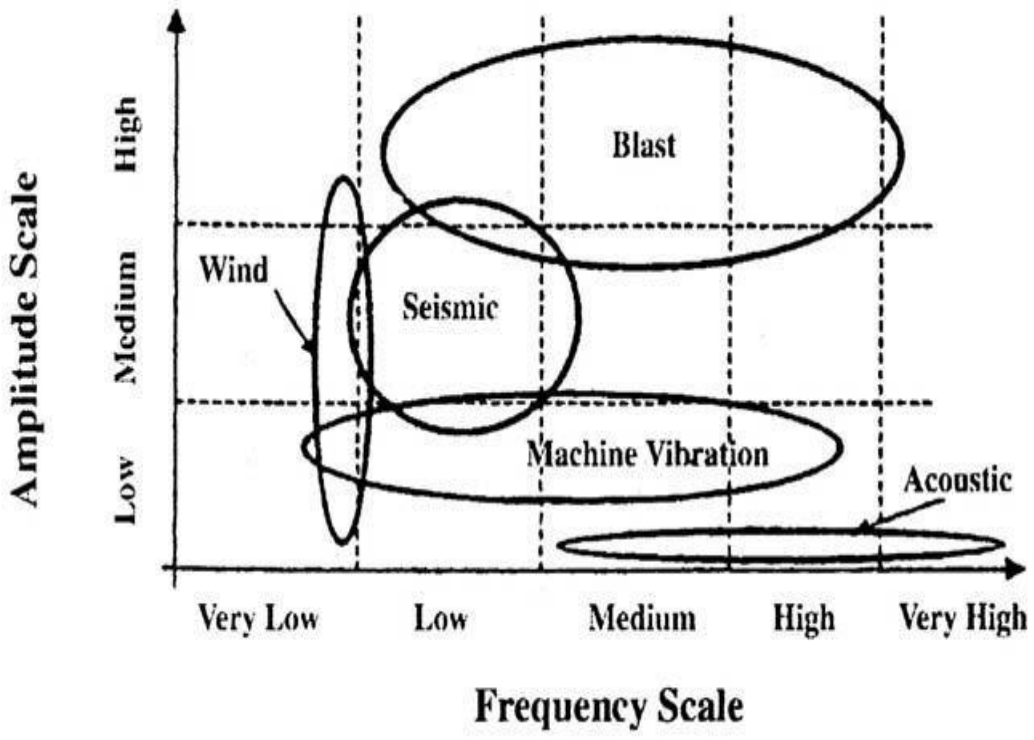


Figure 1.9.Qualitative amplitude-frequency distribution for different hazards[3].

1.6. Outlines of Work

Chapter 1: This chapter discusses the introductory part related to the blast. Types of blast and their effects on the structures are shown.

Chapter 2: This chapter gives the detailed literature survey related to the blast studies. The state-of-art and the state-of-practice on the blast analysis, design and practice in civil engineering is reviewed.

Chapter 3: In this chapter analysis of bridge when subjected to blast loading is given. Methods of the analysis and modeling of the bridge using ETABS is discussed. Suitable bridge parameters are selected to model the bridge and calculations of the loads induced due to blast explosions on bridge structure are done.

Chapter 4: In this chapter results are discussed based on different loading cases. Various conclusions are sorted using these results.

Chapter 5: In this chapter conclusion is given based on the work carried out through work. Future scope is also discussed in this chapter.

CHAPTER 2

LITERATURE REVIEW

Blast studies broadly differ in terms of objective, problem encountered, methodology, expertise and technology required, as well as budgetary restriction and schedule constraints. Consequently, the research findings derived under the discretion of separate investigations, which are either valid exclusively to the specific issues under consideration or justifiable generically to much broader aspects, are not necessarily subject to direct comparison and should always be interpreted independently and perceived as either mutually reinforcing or disagreeing to a certain extent, while absolute generalization should, never be enforced. The blast consequences observed on the individual bridge elements considered are described together with the subsequent impact on the overall integrity of the corresponding bridge systems. The mitigation tactics proposed are discussed, with major emphasis of functions delivered as well as the inherent effectiveness. Further, enquires to be carried out for the future development of engineering field is also identified.

Explosive devices have been used for hundreds of years, yet comprehensive treatment of blast-effects and their mitigation appeared in the Western Hemisphere only during and after World

War II. Following the war, the Office of Scientific Research and Development [NDRC (1946)] produced the seminal, unclassified document on weapons and penetration capabilities.

Following are some literatures that are studied concerned to the find the research gap.

A.K.M Anwarul Islam, NurYazdani[1] (2006), United States studied on the design methodology and load factors for designing bridge piers against ship impact and vehicular collision using AASHTO specifications. This study investigated the most common type of concrete bridges on the interstate highways. A 2-span 2-lane bridge with Type III AASHTO girders was used for modeling using STAAD PRO. AASHTO Load and Resistant Factor Design methods were used for the model bridge design. The girders, pier caps and column loading were analyzed for probable blast loading. To obtain the model bridge, 226.8kg of TNT was converted into equivalent static loads using AT-Blast. It was found from analytical study that Type III AASHTO Girder Bridge will fail due to probable blast load generated due to 226.8kg TNT. It was determined that Type III AASHTO girders, traditionally designed pier cap and column could not withstand the impact of 226.8kg TNT. In short AASHTO girder bridges with concrete columns and piers are not capable of resisting specific blast load.

Andrew Sorenson, William L. McGill [2] (2012), discusses the results of a review of the existing blast analysis software packages for their ability to be used as a forensic tool supporting post-blast investigations. The recurring limitations of the software found are discussed. Using these software packages the blast design software if used properly, can help with back- calculations of parameters such as charge weight and blast load direction based on blast damage information.

Cimo[3] (2007) created a two span simply supported bridge using ANSYS-AUTODYN. A faster computational speed was attained by remapping the blast pressures obtained from the one dimensional analysis onto the two dimensional space. Unfortunately, the numerical outputs were only recorded up to the instant when the computation was prematurely terminated because of unexpected interface overlapping error.

David G. Winget, Kirk A. Marchand and Eric B. Williamson[5](2005), presented the ongoing researches to develop performance based blast design standards specifically for bridges. This paper had briefly discussed the incorporation of physical security and site layout principles into the design process. It also discusses the potential effects of blast loads on bridges and provides structural design and retrofit solutions to counter these effects. Through the use of simple models similar to those presented in this paper has gained a better understanding of blast effects on bridge components and has prioritize his efforts for experimental studies of the most promising retrofit solutions.

Edmond K.C. Tang, Hong Hou[6]described the bridge under consideration, blast load estimation, finite element model, material model, and detailed numerical simulation results of the bridge to blast loads from a 1000kg TNT equivalent explosion at 0.5 m from the bridge tower and pier, and 1.0 m above the deck. Damage mechanism and severity of the bridge tower, pier and deck are examined. The effectiveness of FRP strengthening of bridge concrete back span for blast load resistance is also investigated.

Fujikura et al. (2008) [7] devised a simplistic approach to predict the blast reaction of the concrete-filled steel tube columns. The kinetic energy delivered by an impulse was assumed to be fully converted into internal strain energy, ignoring spalling and breaching. A reduction factor was introduced to in-corporate close-in blast impact, clearing effect and the influence of strain rate. The blast pressures were calculated from A.T.-BLAST, while the impulse variations along the columns were derived from BEL.

G.Daniel Williams, Eric B. Williamson[8] (2011). The bridge components may be exposed to large blast threats that can be in close proximity to the potential target. To address these situations, experimental and computational research was carried out, through the support from the National Cooperative Highway Research Program (NCHRP), to understand the behavior of blast-loaded concrete bridge member. Using finite element models, this paper has explained the cross sectional response mechanisms that cause spalling of side cover concrete in blast loaded slender reinforced concrete members by numerically reproducing the behavior observed during the experimental testing program. The results of the detailed numerical models were used to explain the mechanism leading to this response. With the ability to predict the extent of spall damage that can occur for a given threat, bridge engineers can ensure that the columns they design have adequate capacity to sustain gravity loads following damage from a blast event.

HrvojeDraganic, Vladimir Sigmund[9], describes the process of determining the blast load on structures and provides a numerical example of a fictive structure exposed to this load. The aim was to become familiar with the issue of blast load because of ever growing terrorist threat and the lack of guidelines from national and European regulations on the verification of structures exposed to explosions. The blast load was analytically determined as a pressure-time history and numerical model of the structure was created in SAP2000. The results confirm the initial assumption that it is possible with conventional software to simulate an explosion effects and give a preliminary assessment of the structure.

Jin Son, Ho-Jung Lee[12]carried out the study with an objective of the performance of hollow steel box and concrete-filled composite pylons of a cable-stayed bridge subjected to blast loads. Car bomb detonation on the deck is assumed to be the most likely scenario to occur. A coupled numerical approach with combined Lagrangian and Eulerian models was used to consider the interaction of the deck and pylon with the air that transfers the explosion effect to the bridge. The non-linear explicit finite element analysis program, MD Nastran SOL700 was used to simulate the spatial and time variation of the blast load as well as blast shock wave– bridge interaction response. The blast resistance of two different types of pylons was investigated in a comparative study. The study established damage patterns of the pylon and showed superior performance of the concrete-filled composite pylon over the hollow steel box pylon. For the hollow steel box pylon, the P–Δ effect on the instability of the pylon subjected to blast load was significant.

Mahoney[13] (2007) applied the blast loads obtained from AT Blast on a long span supported prestressed concrete girder bridge, a three-span simply supported composite girder bridge and a three span cantilever truss bridge, all simulated in SAP2000. The arbitrary blast setups were decided with the aid of Monte Carlo simulation. The consequence assessments were conducted by referring to the structural damage indicated by the performance of the plastic hinges, along with the possible amount of downtime and casualities.

Matthews[14] (2008)built a model of a simple-span simply-supported prestressed concrete girder bridge with ABAQUS. The segments near the supports were assumed to behave in an elastic manner. The deck was also assigned a prestress action, owing to the difficulty in integrating the slab after the introduction of the prestress forces in the girders. The blast inputs were imported from BEL.

N. Moon[15] has done a work on the prediction of blast loading and its impact on buildings and submitted a dissertation report to the national institute of technology Rourkela. That paper gave a comprehensive overview of the effects of explosion on structures. The response of simple RC columns subjected to constant axial loads and lateral blast loads was examined. The finite element package ANSYS was used to model RC column with different boundary conditions and using the mesh less method to reduce mesh distortions. For the response calculations, a constant axial force was first applied to the column and the equilibrium state was determined. Next, a short duration, lateral blast load was applied and the response time history was calculated. Studies were conducted on the behavior of structural concrete subjected to blast loads. These studies gradually enhanced the understanding of the role that structural details play in affecting the behavior. The finite element analysis revealed that, for axially loaded columns, there exists a critical lateral blast impulse. Any applied blast impulse above this value will result in the collapsing of the column before the allowable beam deflection criterion is reached.

Rong-Bing Deng, Xian-Long Jin[16](2009),(China), focused on the numerical simulation of the structural damage of a steel truss bridge subjected to blast loading with ANSYS AUTODYN. For research purpose Minpu II Bridge in Shanghai was selected. A 3-D nonlinear finite element model of an actual bridge has been developed. The effects of mesh size on pressure distribution produced by explosions are also studied. Comparison was made between the calculation results and the experimental values; the reliability of the calculation is validated. Peak overpressures between empirical relations and numerical values using a mesh guarantees the effectiveness of blast loading and reliability of computational results. It illustrates the characteristics damage effect corresponding to the general law of explosion. The numerical results give a global understanding of bridge under blast loading.

S. Fujikura and M. Bruneau[17](2006, 2011), presented the development and experimental validation of a multi-hazard bridge pier concept. The proposed concept was multi column pier-bent with concrete-filled steel tube (CFST) columns. The research was to examine seismically resistant bridge piers that are designed according to current seismic knowledge and that are currently applied in typical highway bridge design. It was found that by current seismic codes reinforced concrete give satisfactory seismic performance, thus shown ineffective for the blast loading cases. Only the compressive region of the pier was of interest, while the contribution from the reinforcing steel was ignored.

SomnathKarmarkar[18] carried out study of Reinforced Concrete Bridges & its response under blast loading to determine the weight of explosive required for causing damage. For certain time duration of blast loading, time-history analysis is carried out by considering reinforced concrete as visco-elasto plastic tension softening materials and using Newmark's Predictor-Corrector algorithm. In this investigation, an analytical model has been chosen and analyzed for the generalized blast loadings. It was concluded that the most sensitive zone vulnerable to damage by R.D.X is located near about the mid span and that close to the outer girder.

Son and Lee[19] (2011), which was related to an existing cable stayed bridge, involved a concrete-filled composite pylon and a hollow steel pylon. The FSI simulations were implemented in MD Nastran SOL700. Only the tower and the steel orthotropic deck were extracted for the blast simulation, while the absence of the cables was compensated by introducing axial compressive forces and allowing only horizontal translation at the longitudinal ends. A total of four Euler subdivisions were formed in order to govern the flow movement activated upon structural failure.

Suthar[20](2007) carried out study on a suspension bridge model in SAP2000. The blast loads taken from AT-BLAST were treated as equivalent static loads. The progressive collapse analysis was conducted by relying on the formation of plastic hinges at the top and bottom chords of the trusses.

T.W.Y Lua, P. Mendis[21] carried out blast effects investigations from various different studies and literatures. He employed the simplistic and advanced theoretical and practical investigation strategies. The blast consequences observed on the individual bridge elements considered are described together with the subsequent impact on the overall integrity of the corresponding bridge systems. The mitigation tactics proposed are discussed, with major emphasis on the functions delivered as well as the inherent effectiveness.

Wei Wang, Ruichao Liu, Biao Wu[23] (2013), China, analyze the structural failure of a bridge caused by an accidental fireworks explosion. The equivalent mass of TNT explosive and structural response of the bridge due to the dynamic load imposed by the explosion is modeled by engineering algorithms and numerical simulations. The integrated computer hydrocodes such as ANSYS AUTODYN software is used to conduct numerical analysis successfully. The research shows that the accident was caused by the firework and not by a bridge design defect. The presented damages and their mechanism provide new insights into explosion damages.

Williamson E.B. & Marchand[24] focused on the study of a modern cable stayed bridge under blast loadings. In order to investigate the non-linear behavior of the cable stayed bridge, three dimensional finite element models have been developed using LS-Dyna. Both strain rate effect and the equation of state for the concrete material have been incorporated into the aforementioned numerical models to ensure a more reliable response prediction under extreme blast impacts. The analysis was conducted to examine the failure of 4 components of bridge viz., pier, tower, concrete back span & steel composite main span under dynamic impact of a 1000kg TNT equivalent blast load, Further same was tested under US Department of Defence guidelines to investigate the possibility of bridge collapse after damage of these components. It was found that failure of vertical load bearing bridge elements will lead to the catastrophic failure or collapse of the bridge.

Yuxin Pan. Ben Y.B. Chan, Moe M.S. Cheung[25](2013), a multi-Euler domain method to solve the problems listed earlier. Both the verification of the method and its application for a RC composite slab-on-girder bridge proved its accuracy and efficiency. The blast-resistant capacity of three different detonation scenarios was investigated, including one above-deck detonation and two under-deck detonations, with different trinitrotoluene (TNT) equivalent charge weights. This study established the dynamic performance and the damage mechanisms of the whole bridge and identified the critical blast event for this typical slab-on-girder bridge. Yuxin has developed a multi-Euler domain and applied for blast effects simulation of a RC composite slab-on-girder bridge. By using the proposed method, the large and complex structural response of bridges under blast loading can be analyzed based on a fully coupled Lagrange-Euler interaction finite-element model. This study has presented a preliminary analysis of the performance of a RC girder bridge under different proposed threat scenarios. Because the numerical simulation of blast loading is highly sensitive to the nature of the explosive material and the nonlinearity associated with RC structures, more investigations are necessary to achieve a more systematic and comprehensive scheme to counter the threat to critical infrastructures in the future.

Z. Yi, A.K. Agrawal, M.Ettouney, and S. Alampalli[26], (2009), (New York), introduced a new approach for application of blast loads on bridge components. This approach can apply realistic loads and can simulate both reflection and diffraction of blast loads. Verification of simulation of blast loads in LS-DYNA has been carried out by using available tests on beams. A typical three span reinforced concrete bridge highway bridge has been developed for investigation of blast load effect. Simulation results shows that bridge components such as elastomeric bearings are subjective to excessively high levels of stresses during a high level of blast loads.

ZhihuaYi, Anil K. Agrawal[27] (2009),In this report, author have presented a new approach to generate blast loads by Con-Wep and transmit it through air medium to structural components. In order to investigate effects of blast loads on bridge components, a very detailed finite element model of the bridge with approximately 1 million degrees of freedom has been developed. The bridge has been subjected to three levels of blast loads, designated as Low, Medium and Large. In order to investigate correlations between seismic detailing, concrete strength and blast load magnitude, the bridge model has been designed for three different seismic regions with concrete compressive strength varying from 3,000 to 10,000 psi. Based on simulation results, 14 damage mechanisms prominent during blast load effects on bridges have been identified and correlated with seismic damage mechanisms. Simulation results show that seismic capacities and blast load effects are strongly correlated. Better seismic capacity directly implies better blast load resistance. However, several damage mechanisms are not present during seismic loadings and protect ion of bridge components from failure because of these mechanisms needs to be considered by improved detailing of components and optimization for multi-hazard seismic blast designs.

Summary:

After reviewing all the above literatures it can be noted that blast intensity and its effect on structures cannot be predicted accurately as charge location and amount may vary. The effects and deformations due to blast are so intense that in most cases of carried researches, the structures get fully collapsed. Design of the structures considering high blast pressures and it becomes more complex, heavy and proves to be uneconomical in nature. Most of the researches have been carried out for different structures for different cases of charge weights and stand-off distances. By studying all the above literatures we can conclude that instead of designing heavy and uneconomical structures, securing measures to mitigate the blast effects may be taken.

By studying the above literatures I have focused on viewing the structural behavior of RCC Bridge due to blast for the charge weights at different stand-off distances. All the possible displacements and bending moments of the framed structure were computed by using and finite element package ETABS software (Extended 3D analysis of Building Systems).

CHAPTER 3

METHODOLOGY

3.1. Objective and Present Study:

The experimental verification using scaled models is generally carried out in developing design guidelines for structures subject to hazards such as earthquakes, wind, etc., this is not practical in case of blast loads because of following three reasons.

- It is very difficult to reproduce the same blast wave environment, even in the same test field and using the same amount of explosive charge because of the temperature, humidity and dust condition of the air. Consequently, it is very difficult to carry out systematic experimental study of different parameters affecting behavior of structures subject to blast loads.
- It is difficult to ensure reliability of the data measurements, e.g., strain gauge, displacement sensors, etc., during explosion tests because of large deformation and fragmentation of the test structure.
- Experimental blast tests are also cost-prohibitive and can only be carried out at select facilities.

Because of reasons described above, analytical tools such as hydro-codes have significantly shown more reliability and accuracy in the simulation of blast load effects on structures. Following are some objectives of dissertation.

- To investigate the finite element tools for the simulation of blast load effects on various bridge components of a typical highway bridge.
- To investigate the performance of different components during blast events, identify typical mechanism responsible for causing damage or failure of the components of structure.

3.2. Scope of Study

In order to achieve the objectives given above following tasks can be adopted,

- To use the suitable hydro-codes (i.e., FEM modeling software like ETABS) for the simulation of these blast effects on the various components of bridge.

- To study the dynamic response of the structure for different cases of blast phenomenon. Thus to investigate the study following are the cases that are to be adopted.

1. Vehicle Bomb Blast 1m height above deck.
2. Vehicle Bomb Blast 2m height above deck.

3.3. Effects of Blast on Structures:

The effects of explosions on structures are directly related to stress-wave propagation as well as impact and missile penetration. In all close-in explosions, where shock waves must travel through the surrounding medium to cause damage to a facility a realistic description of the wave-propagation phenomena is needed. The effects of explosion are varied. For explosions close to the targeted object the pressure-driven effects occur quickly, in the order of microseconds to a few milliseconds. The air-blast loads are commonly subdivided into

1. Loading due to the impinging shock front, its reflections, and the greatly increased hydrostatic pressure behind the front, all commonly denoted as overpressure and
2. The dynamic pressures due to the particle velocity, or mass transfer, of the air. It is customary to characterize the pressure loadings in terms of scaled range, given by

$$Z = R / W^{1/3} \tag{3.1}$$

Where,

Z is the scaled range,

R is the radial distance between the explosion center and the target and

W is the explosive weight (normally expressed as an equivalent TNT weight).

Units for charge weight and distance should be pounds and feet.

If an explosion is confined by a chamber or room, the gas pressure increases rapidly to a sustained level and then decays because of venting out. Under these conditions, shock reflections occur and the overall effect can be greater than that of the incident shock pressure. The effects of internal explosions can be devastating to buildings and their occupants. There is a considerable body of knowledge available concerning blast-effects mitigating techniques for buildings subject to accidental explosions, which may have applicability to the design of civilian office structures, bridge box girders, etc.

If the explosion originates at a sufficiently great scaled range (i.e., a small charge or a large distance from a structure), then the structure will be loaded in a manner that leads to global deformation, meaning that all the elements provide some degree of resistance to the loading. Dynamic analysis and design in such cases depends on the expected loading and the provision of resisting elements to accommodate the loading.

If the explosion is sufficiently close to a pier or deck (that is, with a small scaled range Z), there can be gross disintegration of structural components, with either spalled fragments coming off the front and back sides or wall fragments themselves being propelled as missiles. These fragments can injure people, damage property, and cause the structure to collapse if the structural support is sufficiently disrupted. At intermediate scaled ranges, both global and localized response, including severe cracking, with near-face disintegration and spalling on the rear face, can be expected. When an explosion impinges on a structural element, a shock wave is transmitted internally at high speed. For example, dilatational waves (tension or compression) propagate at speeds in the range of 2,700-3,400 m/s in typical concrete and 4,900-5,800m/s in steel. At these speeds, reflections and refractions occur quickly within the material (within milliseconds), and, depending on the material properties, high-rate straining and major disintegration effects can occur. For example, under extremely high shock pressures, concrete, a relatively brittle material, tends to undergo multiple fractures which can lead to fragmentation. In steel, under similar conditions, depending on the material properties and geometry, yielding and fracture can be expected, especially if fabrication flaws are present, with fragmentation occurring in some cases. Primary fragments are produced when a detonating explosive is in contact with materials such as concrete or steel. Initial velocity of the primary fragments depends in part on the detonation pressure. Secondary fragments are produced by the effect of the blast wave on materials not in contact with the explosive. Other explosion-generated effects are also produced, such as fire (including smoldering fires), smoke, pressure damage to ears and other organs, and violent motion of the structure and its contents. Such shock-related motion can result in personal injury, equipment damage and can cause the loss of lifelines such as utilities and communications cables. Specially, the consequences of attack expressed as damage to bridges and tunnels that are of concern are as follows:

1. Threats to the integrity of the structure (e.g., resulting in replacement of the facility or major repairs).
2. Damage that inhibits the structure’s functionality for an extended period of time, such as closure of the facility for 30 days or more.
3. Contamination of a tunnel resulting in extended closure or loss of functionality.
4. Catastrophic failure resulting from an attack based on the threats.

3.4. Methods for the Analysis of Blast Effects:

Although explosion experiments are very important in the analysis of blast load effects of structures, computer models and programs have become indispensable in characterizing blast load effects. The complexity and dependability of the model varies dramatically.

3.4.1. Experimental Methods

Experimental data may be combined with certain aspects of explosion theory to properly characterize material behavior at high strain rates, which in turn can be used in developing computational approaches for estimating effects of blast loads. Nevertheless, it is important to validate these computational results using experiments involved scaled or full models of structures subject to blast loads. Several researchers have presented results based on blast testing of structures, e.g., blast tests on 1/4-scale concrete masonry unit (CMU) walls. Most commonly, blast tests are carried out on scaled models of structures subjected to blast loads generated by explosive charge. In fact, these types of experiments have been used to develop the database for Design and Analysis of Hardened Structures to Conventional Weapons Effects.

3.4.2. Computational Methods

Most of the computational models are based on finite-element or finite-difference methods. Finite-element methods have the versatility to deal with complicated geometries. In finite-difference methods, the discretization is accomplished by superimposing a network of nodes or grid points on the geometry. The arrangement of these grid points is usually structured, which diminishes the versatility in dealing with complex geometries, but these methods generally offer higher computational speed. Blast load simulations are generally carried out by first-principle and semi-empirical methods. In first-principle programs, mathematical equations describing basic laws of physics, e.g., laws of conservation of matter, momentum, and energy, are solved. In addition to these equations, constitutive equations describing physical behavior of materials are also needed. Semi-empirical computational methods are based on simplified models of physical phenomena, which are developed through analysis of test results and application of engineering judgment. Simulation of blast load effects on structures is highly nonlinear because of behaviors such as fracture, fragmentation, and flow due to high-pressure sources. Besides this, there are many mathematical and physical complications and phenomena whose underlying physics is not well understood, e.g., behavior of different types of joints and connections during blast loads.

3.5.Codal Provisions:

3.5.1.General Characteristic of Blast

3.5.1.1. Source

The conventional chemical charge is considered spherical. The shock front at the ground surface from a contact burst is considered almost vertical. The effective yield of the contact burst is almost double of an equal explosion high in the air. This condition is assumed to give most serious effect[10].

3.5.1.2. Shock Wave

As a result of explosion, a shock wave is generated in the air which moves outward in all directions from the point of burst with high speed causing time-dependent pressure and suction effects at all points in its way. The shock wave consists of an initial positive pressure phase followed by a negative (suction) phase at any point as shown in Figure.3.1. The shock wave is accompanied by blast wind causing dynamic pressures due to drag effects on any obstruction coming in its way. Due to diffraction of the wave at an obstructing surface reflected pressure is caused instantaneously which clears in a time depending on the extent of obstructing surface[9].

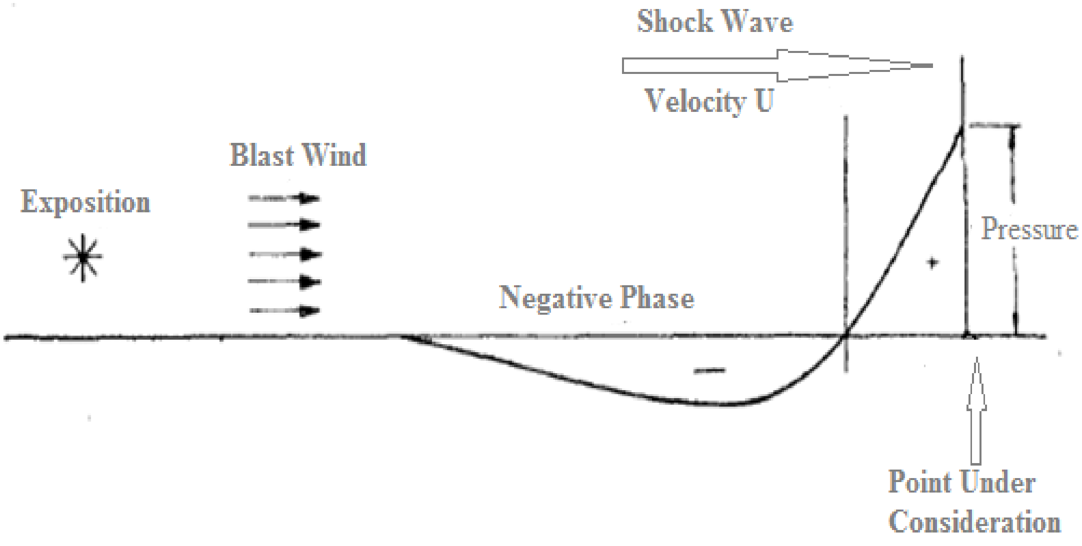


Figure3.1.Shock Wave produced by Blast [10]

3.5.1.3. Pressure and Duration

At any surface encountered by the shockwave, the pressure rises almost instantaneously to the peak values of side-on overpressure and the dynamic pressure or their reflected pressure. The peak values depend upon the size of explosion, the distance of the surface from the source, and other factors like ambient pressure and temperature in air.

The incident blast wave characteristics are described by the peak initial overpressure p_{so}, the overpressure p_R versus time t curve; the maximum dynamic pressure q_o**,** the dynamic pressure q verses time t curve and the duration of positive phase t_o.

The peak positive intensity quickly drops down to zero; the total duration of the positive phase being a few milliseconds. The maximum negative overpressure is much smaller than the peak positive overpressure, its limiting value being one atmosphere. But the negative phase duration is 2 to 5 times as long as that of the positive phase[10].

3.6. Blast Loads

When explosives are detonated, the chemical reaction of the explosives produces a high pressure and high temperature gas. This gas pressure, also known as detonation pressure, propagates like shock and stress wave, and destroys surrounding structures. When the wave front moves forward with a spherical shape, it encounters discontinuities. At this point, some energy is transferred across and some is reflected back. During and after the stress wave propagation, high pressure and high temperature gases extend the radial cracks, any discontinuity, and fracture or already weakened joints. The explosive energy always takes the path of least resistance. Once the blasted portion of the structure is separated, no further fracturing occurs because the gas pressure escapes through the gaps. This entire process occurs within a few milliseconds (m-sec) from the detonation of the explosives.

The initial step in blast design or analysis is the determination of the blast load. Blasts are among the most powerful extreme loads. Even small amount of explosives can inflict sizeable amount of damage to a structure if they are set in the right location. In assessing the performance of bridges under explosion, issues that demand attention include energy absorption, safety factors, limit states, load combinations, resistance functions, structural performance considerations of critical elements, and most importantly, structural redundancy to prevent progressive collapse of the structure.

The effect of the shock wave, which travels away from the explosion faster than the speed of sound, poses the hazard at close-in locations. The shock front is similar to a moving wall of highly compressed air, and is accompanied by blast winds. When it arrives at a location, it causes a sudden rise in the normal pressure. The increase in atmospheric pressure over normal values is referred to as overpressure, and the simultaneous pressure created by the blast winds is called dynamic pressure. Both decay rapidly with time from their peak values to normal pressure and overpressure actually sinks below the normal before equalizing back to normal atmospheric pressure. The overpressure causes hydrostatic-type loads, and the dynamic pressure causes drag or wind type loads. High reflected pressures are generated on surfaces that the shock front strikes head-on or nearly head-on. At a given distance from ground zero, overpressures and dynamic pressures decay with time but may last for several seconds. The time the reflected pressure takes to clear a point on a surface depends mainly on the distance to the closest free edge of the bridge from the point of explosion, and may take as little as one millisecond. Due to their sudden application and relatively long duration, loads produced by overpressure and dynamic pressure can be more critical than equivalent static loads, but the damaging effects of the even higher reflected pressure is reduced by their short lives.

Blast pressure can create loads on structures that are many times greater than normal design loads, and blast winds can be much more severe than hurricanes. Dynamic pressure may continue to cause drag loads on the structural frame that is left standing. If detonation occurs on top of the bridge, deck slab will experience the downward thrust of the overpressure, which will be transmitted to the supporting girders, pier cap and columns. Foundations will experience blast induced vertical and overturning forces. If blast load is applied at the bottom of the bridge, pier cap, pre-stressed girder and deck slab will be subjected to vertically upward pressure for which they are not generally designed.

3.6.1. Basic Parameters of explosion

Use of TNT (Trinitrotoluene) as reference for determining the scaled distance Z, is universal. The first step in quantifying the explosive wave from a source other than the TNT, is to convert the charge mass into an equivalent mass of TNT. It is performed so that the charge mass of explosive is multiplied by the conversion factor based on the specific energy of different explosives types and their conversion factors to that of the TNT are given in Table 3.1.

Table 3.1. Conversion factors for explosives[1]

Explosive	Specific Energy (Q_x/ kJ/kg)	TNT equivalent (Q_x / Q_{TNT})
Compound B (60% RDX, 40% TNT)	5190	1.148
RDX (Ciklonit)	5360	1.185

HMX	5680	1.256
Nitroglycerin (liquid)	6700	1.481
TNT	4520	1.000
Explosive gelatin (91% nitroglycerin, 7.9% nitrocellulose, 0.9% antracid, 0.2% water)	4520	1.000
60% nitroglycerin dynamite	2710	0.600
Semtex	5660	1.250
C4	6057	1.340

3.6.2.Structural Response to Blast Loading

Complexity in analyzing the dynamic response of blast-loaded structures involves the effect of high strain rates, the non-linear inelastic material behaviour, 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.

3.6.3. Comparison between Blast and Seismic Loading

Similarities and differences between seismic and blast loading are noticeable. Both of these loads are dynamic loads and they produce dynamic structural response. The structural behaviour in response to these loads is inelastic as well. The focus of structural design against these loads is on life safety as opposed to preventing structural damage. Therefore, the designs are normally performance based that include life safety issues, progressive collapse mechanisms, ductility of certain critical components, and redundancy of the whole structure. In certain circumstances, these loads may not damage structures, but can still claim human lives and create natural hazards. Blast loads are applied over a significantly shorter period of time (orders-of- magnitude shorter) than seismic loads. Thus, material strain rate effects become critical and must be accounted for in predicting connection performance for short duration loadings such as blast. Also, blast loads generally will be applied to a structure non-uniformly, i.e., there will be a variation of load amplitude across the face of the building, and dramatically reduced blast loads on the sides and rear of the building away from the blast. Figure 3.2 shows a general comparison between seismic load and blast load.

Differences between these two types of loadings are presented in Figure. 3.2. and summarized in Table 3.2. Blast load damages structures through propagating spherical pressure waves, while earthquake damages structures through lateral ground shaking. Spherical pressure due to explosion directly hits structures and causes failure, but seismic load causes lateral load effect on structures through ground movement.

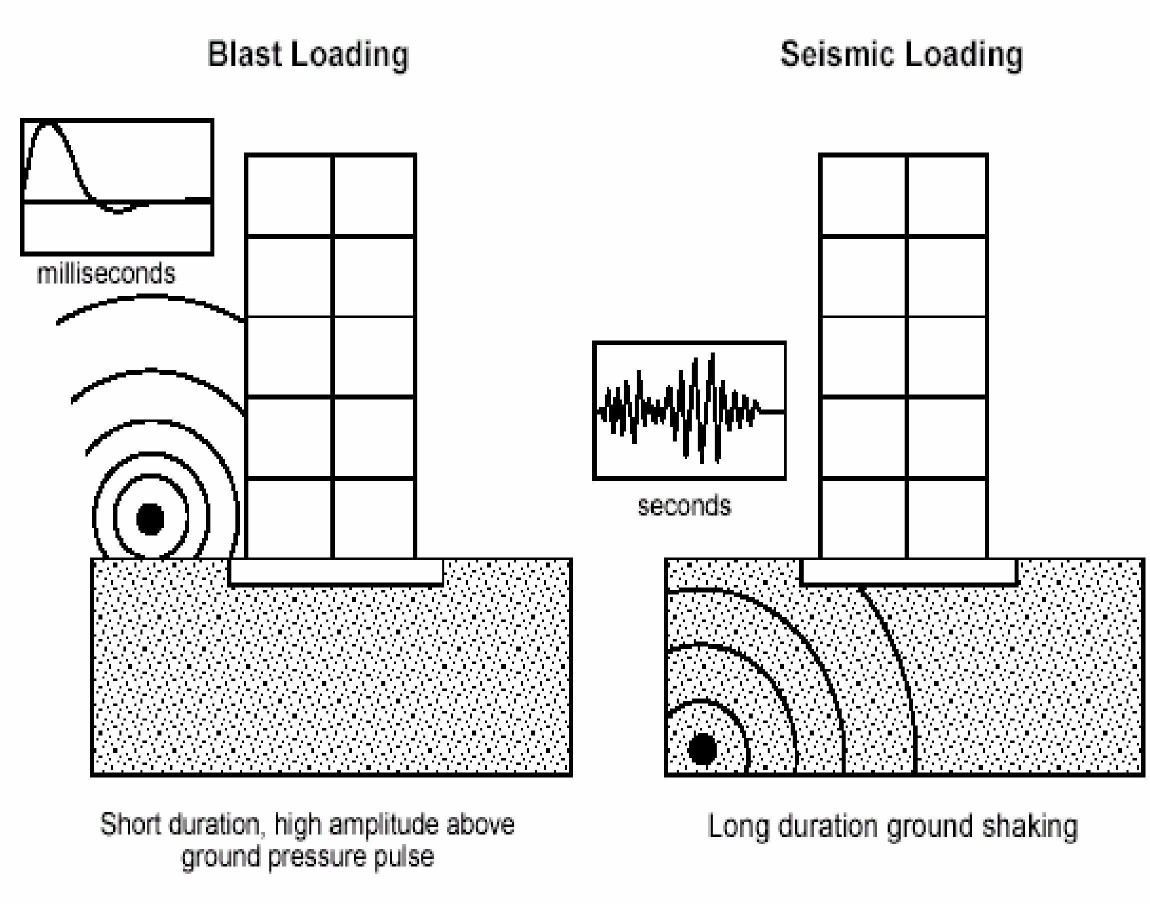


Figure 3.2.Comparison between Blast and Seismic action.

Table 3.2.Difference between Blast Load and Seismic Load

Blast Load	Seismic Load
Damages structure through propagating spherical pressure waves.	Damages structure through lateral ground shaking.
Higher amplitude if explosion is targeted on a particular structure.	Not targeted on any particular structure.

Directly hit the structure.	Seismic epicentre develops few miles down from the ground surface.
Shorter duration in terms of milliseconds.	Longer duration in terms of seconds.
Highly unpredictable.	Highly unpredictable, but can be precisely described in the aftermath of an earthquake.
More localized action.	More global action.
Does not depend on geographic location.	Entirely depends on geographic location.
Can be categorized by standoff distance and charge weight.	Can be categorized by geographic locations.
Can be prevented by implementing necessary security measures.	Cannot be prevented.

3.7. Problem Statement

In this study a simply supported continuous bridge is taken having a RL of 97.165m from MSL. Bridge consists of 3 equal spans having a length of 24m each. It contains 2 piers and 2 abutments spaced at 24m c/c. Deck slab is supported by the girder with girder beams throughout the span width. IRC Class B loading is assumed on the bridge. The columns of the bridge are supported by footings. Elastomeric Bearings are used below the girder to sustain the stiffness of the structure. The structure is modeled in the finite element modeling design software ETABS. Different cases of the explosive materials are taken at different distances with TNT explosives. These charges are allowed to detonate above the deck slab of bridge. The impact pressure acting on the deck is then calculated using TM 5-1300 and IS: 4991-1968. The same pressures are the applied on the affected areas through software and displacements at nodes, stresses, bending moments and the deformed patterns are then computed.

3.8. Modeling of Bridge

3.8.1.Basic Bridge Parameters:

The initial step to carry out the study is to model the bridge. Following are the parameters of the modeled bridge.

1) Total Length of the bridge = 72m.

2) Total width of bridge = 8.95m including 2 lanes with clear carriageway of 8m, and side barriers of 475mm on both sides.

3) Clear carriageway = 8m

4) No. of piers = 2nos.

5) No. of abutments = 2nos.

6) Concrete diaphragm or caps are used over the piers to enhance the continuity of the bridge.

7) Elastomeric bearings are provided below the girder.

8) Thickness of deck slab= 250mm.

9) Reduced Level of bridge= 97.165m w.r.t MSL.

10) The bridge lies in Seismic Zone II and assumed for moderate exposure.

11) IRC Class A loading or single lane of IRC 70R loading whichever produces worst effects is taken.

12) Size of Girder = b X D = 400 x 1000mm.

13) Grade of concrete used is M-40.

14) Size of Column = 1.2m diameter having a reinforcement cover of 70mm.

15) Size of Beam = b x D = 500 x 1000mm below girder and for deck with reinforcement cover of 30mm.

Mechanical Properties:

Table 3.3.Mechanical Properties

Material	**Element**	**f_c(Mpa)**	**Poisson's ratio**	**W_c (kg/m^2)**	**E_c(MPa)**
Material 1	Girder, Deck slab, Column	40	0.2	2400	31,650

Where,

f_c = 28 days compressive strength of concrete

W_c= Unit weight of concrete.

E_c = Modulus of elasticity of concrete.

Using these parameters for the further analysis, the bridge is modeled using design software ETABS (Extended 3D analysis of structures).

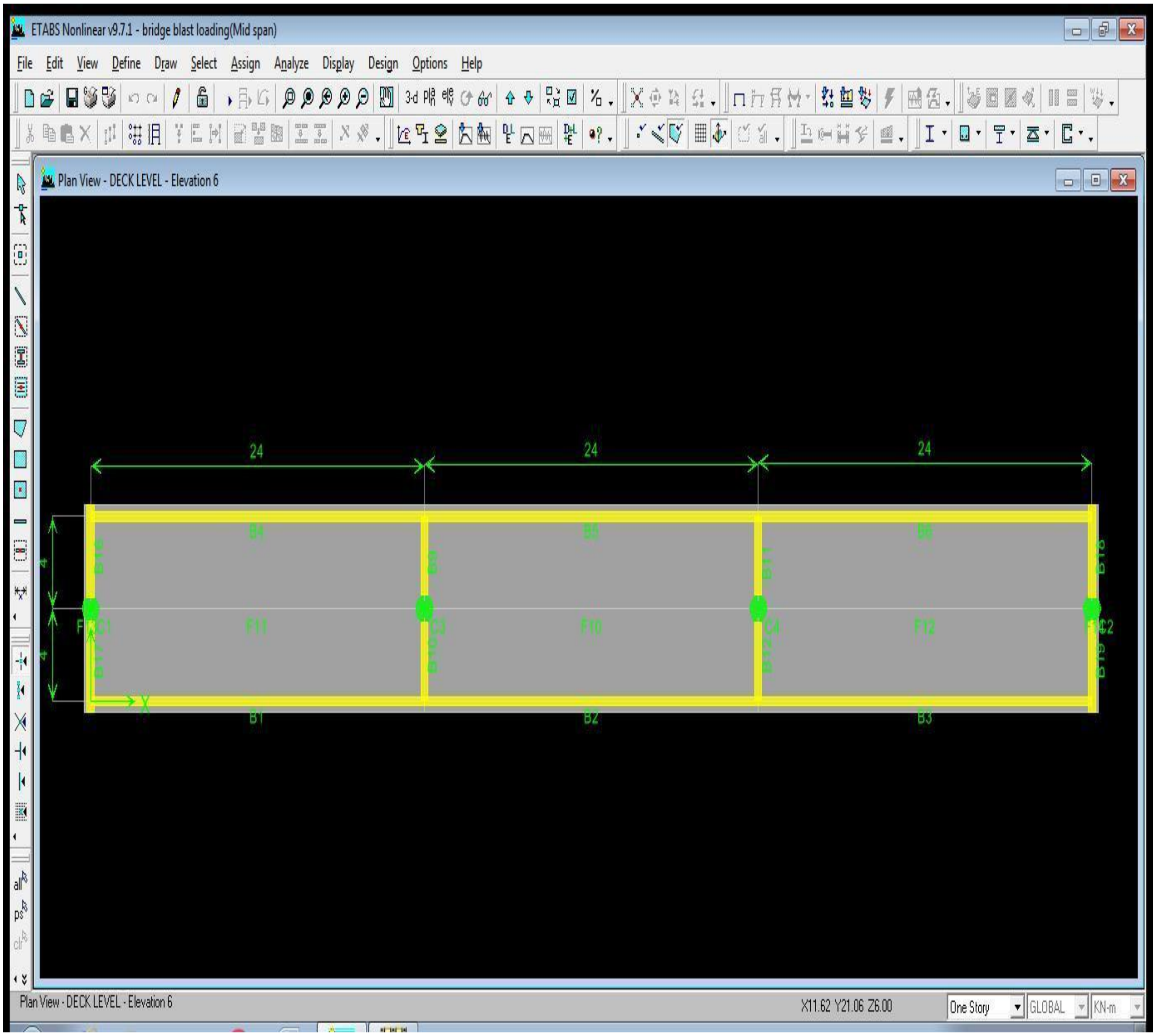


Figure3.3.Plan of Modeled bridge.

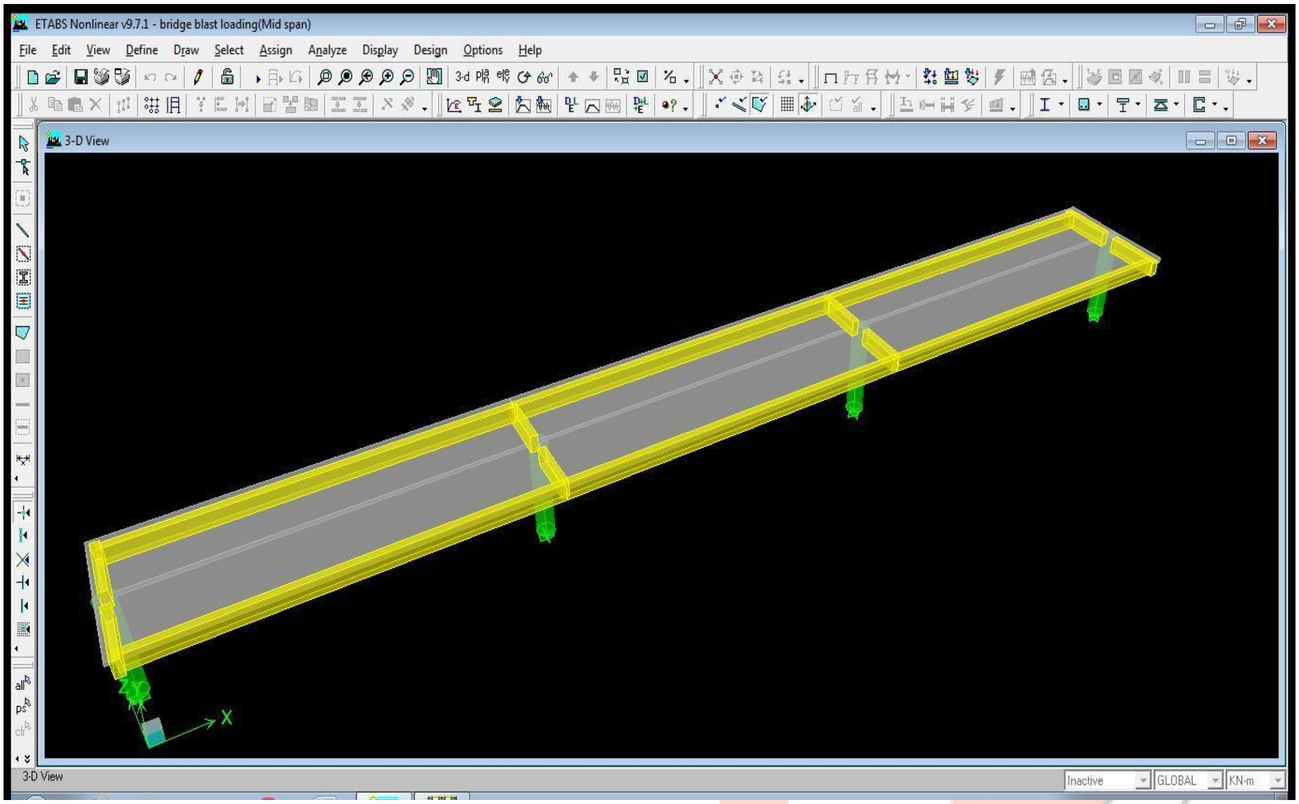


Figure 3.4. 3D Elevation of Modeled bridge.

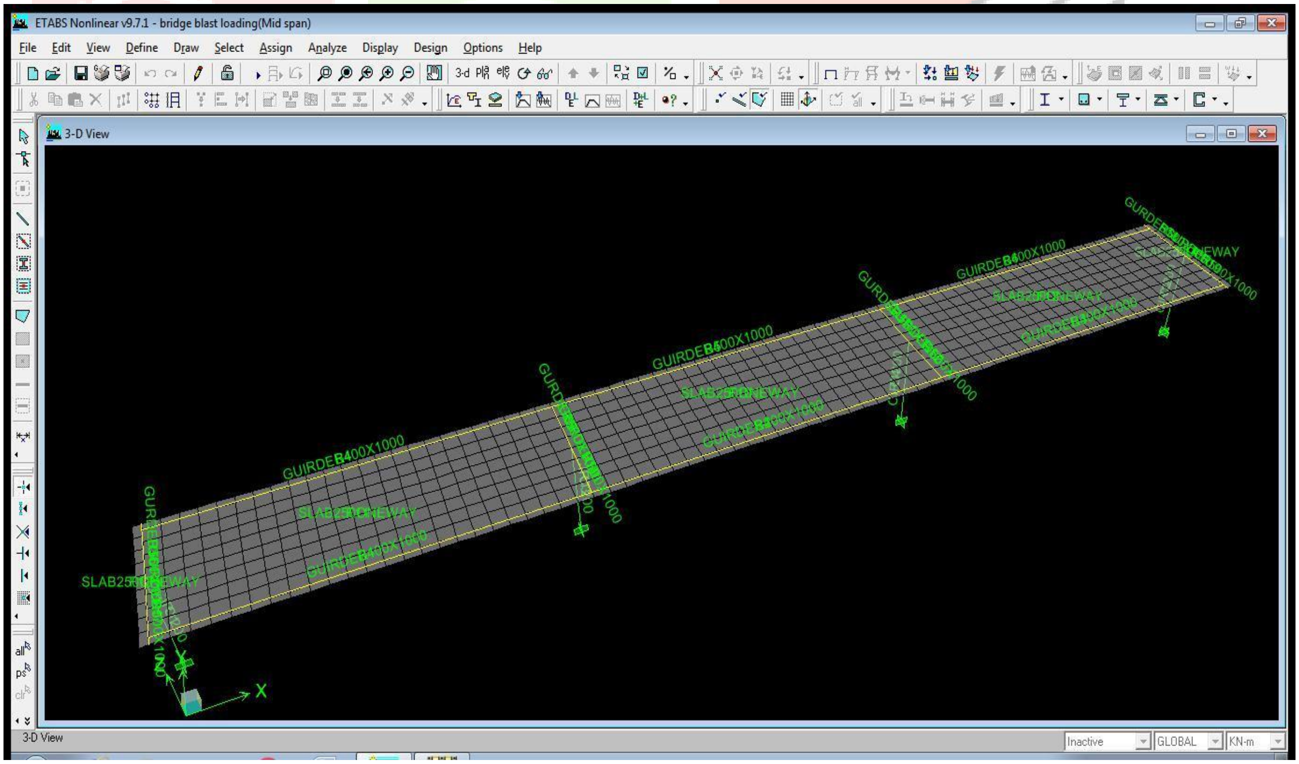


Figure 3.5. 3D view with section details and object meshing.

3.8.2. ETABS Software

ETABS is a powerful program that can greatly enhance an engineer's analysis and design capabilities for structures. ETABS is an engineering software product that caters to multistory building analysis and design. As it is a powerful program part of that power lies in an array of options and features. The other part lies in how simple it is to use. The basic approach for using the program is very straight forward. Modeling tools and templates, code based load prescriptions, analysis methods and solution techniques, all coordinate with the grid-like geometry unique to the class of the structure. User establishes grid lines, places structural objects relative to the gridlines using joints, frames and shells, and assigns loads and structural properties to those structural objects (for example, a frame object can be assigned section properties; a joint object can be assigned spring properties; a shell object can be assigned slab or deck properties). Analysis, design, and detailing are then performed based on the structural objects and their assignments. Results are generated in graphical or tabular form that can be printed to a printer or to a file for use in other programs. Basic or advanced systems under static or dynamic conditions may be evaluated using ETABS. For a sophisticated assessment of seismic performance, modal and direct integration time-history analyses may couple P–Δ and large displacement effects. The intuitive and integrated features make ETABS a coordinated productive tool for designs which range from simple 2D frames to elaborate modern high rises.

ETABS provides a number of templates that allow for the rapid generation of models for a wide range of common types of structures. Those templates serve as a good starting point because they can be modified easily. The program includes default parameters, many of which are building code specific. Those defaults are accessed using "Overwrites" and "Preferences." The possible options available for overwrites and the default values for preferences are identified in the design manuals. By using the built-in templates and defaults, the user can create a model in a matter of minutes.

3.8.3. SAFE Software.

SAFE is the ultimate tool for designing concrete floor and foundation systems. From framing layout all the way through to detail drawing production, SAFE integrates every aspect of the engineering design process in one easy and intuitive environment. SAFE provides unmatched benefits to the engineer with its truly unique combination of power, comprehensive capabilities, and ease-of-use.

Laying out models is quick and efficient with the sophisticated drawing tools, or uses one of the import options to bring in data from CAD, spreadsheet, or database programs. Slabs or foundations can be of any shape, and can include edges shaped with circular and spline curves. Post-tensioning may be included in both slabs and beams to balance a percentage of the self-weight. Suspended slabs can include flat, two-way, waffle, and ribbed framing systems. Models can have columns, braces, walls, and ramps connected from the floors above and below. Walls can be modeled as either straight or curved.

A nonlinear cracked analysis is available for slabs. Generating pattern surface loads is easily done by SAFE with an automated option. Design strips can be generated by SAFE or drawn in a completely arbitrary manner by the user, with complete control provided for locating and sizing the calculated reinforcement. Finite element design without strips is also available and useful for slabs with complex geometries. Comprehensive and customizable reports are available for all analysis and design results. Detailed plans, sections, elevations, schedules, and tables may be generated, viewed, and printed from within SAFE or exported to CAD packages.

SAFE provides an immensely capable yet easy-to-use program for structural designers, providing the only tool necessary for the modeling, analysis, design, and detailing of concrete slab systems and foundations.

3.8.4. Elastomeric Bearings.

There is good reason for this. They support vertical loads with minimal compression, allow expansion and contraction of the structure with minimal resistance and provide for normal end rotation of bridge beams. In addition, they are easily installed and maintenance-free.

Bearings are normally mounted with their short side parallel to the girder axis for maximum rotation capacity. However orientation at any angle in the horizontal plane will not affect the shear resistance. Friction pad is usually sufficient to keep bearings in place, but if minimum loads are light, then a slippage check must be made. Friction coefficient of 0.2 is used between elastomer and steel or pre-cast concrete. A coefficient of 0.3 may be used for elastomer against broom-finished concrete or similar roughened surface. More sophisticated designs can be incorporated into an integrated structural system that channels horizontal loads to strong points and away from weaker ones. Ultimately such systems are used to mitigate the severe loading conditions caused by earthquakes.

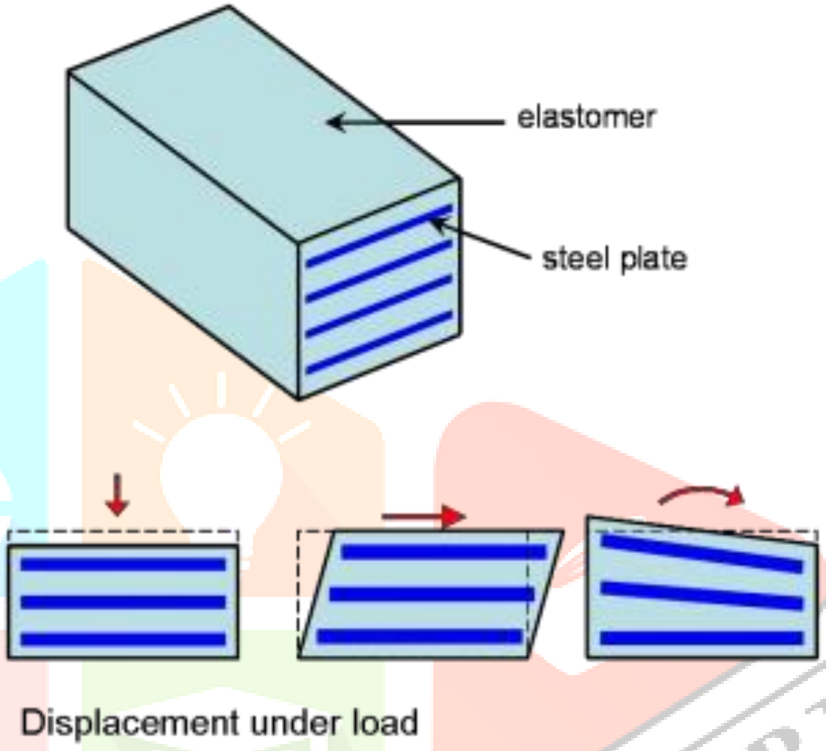


Figure 3.6.Displacement of Elastomeric bearing under loads.

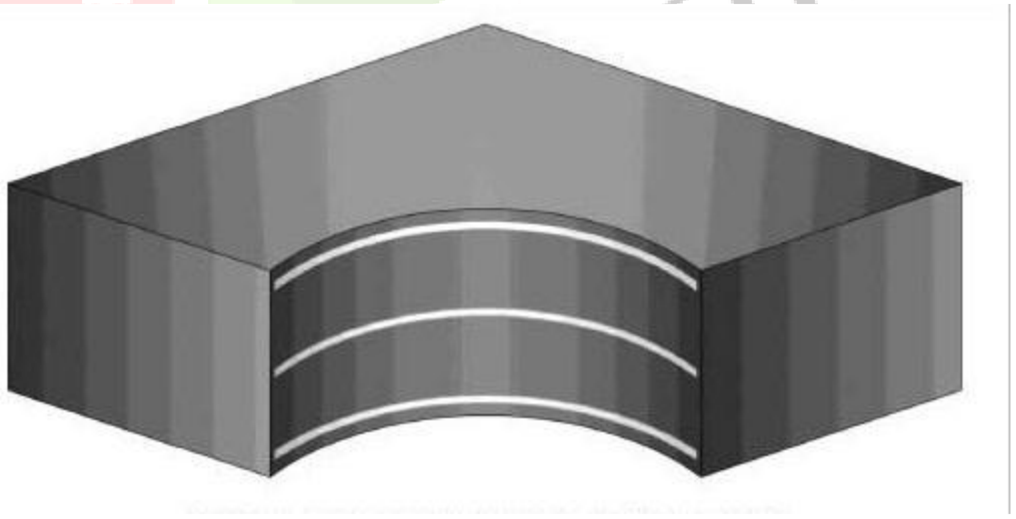


Figure 3.7.Typical elastomeric bearing.

Figure 3.8.Installation of Elastomeric bridge bearing under girder.

3.8.5. Calculations of the Blast pressure

1. The dynamic pressure at the detonation wave-front is the detonation pressure p_1 given in kilo-bars by the empirical equation,

$$\mathbf{p_1 = 2.5 \times 10^{-9} D^2} \tag{3.2}$$

where,

ρ (kg/m^3) is explosive density and

D (m/s) is detonation wave speed.

2.In terms of scaled range the blast loading converted into dynamic pressure is characterize as given in equation 3.1,

Where,

Z is the scaled range,

R is the radial distance between the explosion center and the target and

W is the explosive weight (normally expressed as an equivalent TNT weight)

3**.** Brode (2005) analyzed the results for the peak static overpressure p_s in the near field (for $p_s > 10$ bar) and medium to far field (for p_s between 0.1 to 10 bar)

$$p_s = \frac{6.7}{Z^3} + 1 \text{ bar} \quad (p_s > 10\text{bar}) \tag{3.3}$$

$$p_s = \frac{0.975}{Z} + \frac{1.445}{Z^2} + \frac{5.85}{Z^3} - 0.019 \text{ bar } (0.1 < p_s < 10) \tag{3.4}$$

where, Z is scaled distance from eq^n3.1

From equation 3.1 it is seen that Z is a constant of proportionality and as long as its magnitude remains same, the same parameter for the explosive effects like peak overpressure, positive duration, pressure time scale should be acquired[9]. The specification of scaled distance is useful for efficient determination of blast wave for a wide range of scenarios which is employed by manual TM5-1300 as shown in figure 3.9.

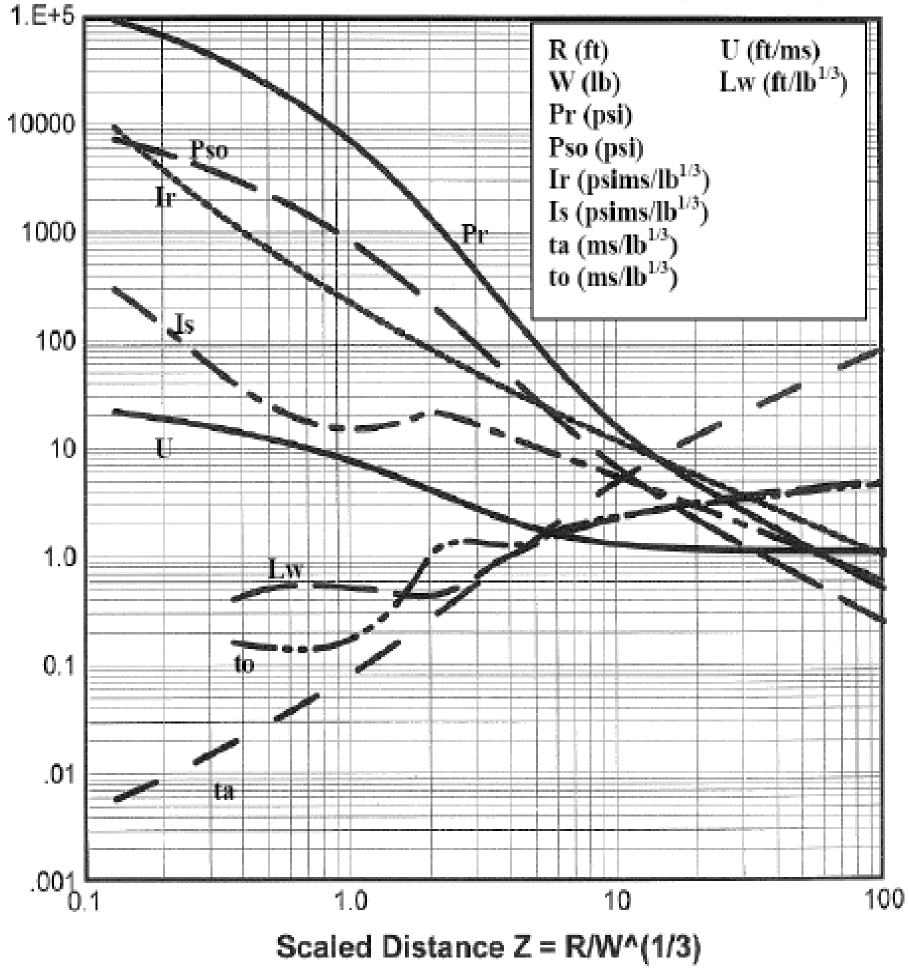


Figure3.9. Positive shock wave parameters at various scaled distances(TM5-1300)

3.8.6. Equivalent Static Load

The method of determining equivalent blast load due to an explosion is a complex phenomenon. The blast pressure diminishes with distance from the point of explosion. In TM 5-1300 manual, Structures to resist the Effects of Accidental Explosions, developed by the US Department of Defense, an empirical formula is given to find the scaled distance. The amount of blast pressure generated due to an explosion is inversely proportional to the scaled distance, which is presented in a chart in the TM 5-1300 manual. The formula is given as,

$$Z = R / W^{1/3}$$

Finding the scaled distance Z, using the above formula foe known values of R and W, amount, of blast pressures can be computed from the chart showing the variation of blast pressure with scaled distance. Further these pressures are converted into equivalent static loads. According to the Blue Panel Ribbon on Bridge and Tunnel Security, the highest possibility of a conventional truck bomb is equivalent to 500lb (226.8 kg) of TNT explosive. For the explosion near the structure it is reasonable to assume that a regular vehicle carrying explosive cannot go closer than 1.22m, and hence the minimum standoff distance is taken herein. The maximum range in this model analysis is 8m, beyond which the impact of the probable explosion is found negligible. When the vehicle is travelling from deck it is assumed that truck bed is at 2m height considering the barrier effect and in case of car it is taken 1m above the deck.

To obtain the loads for the modeled bridge, 226.8kg of TNT with minimum and maximum range of 1.22m and 8m respectively, with an increment of 800mm intervals. Fig 3.10 and table 3.4 represents the pressure computation at the intervals.

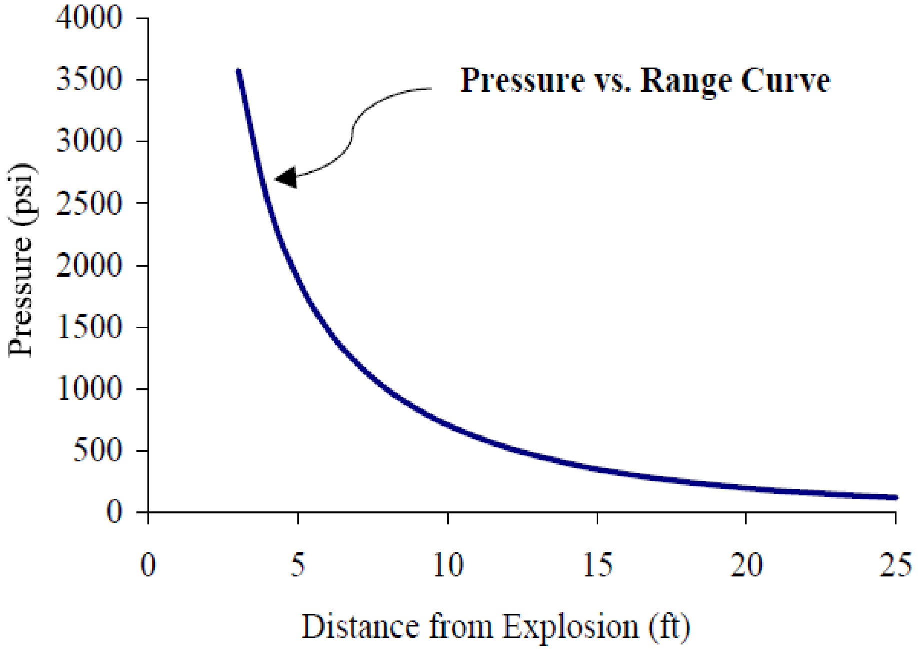


Figure3.10.Variation of Pressure with Distance from Explosion[1].

Table 3.4.Obtained Equivalent Static Pressure for 226.8 kg of TNT explosive.

Range (m)	**Pressure (MPa)**	**Scaled time t_o (milli-sec)**
0.91	24.66	0.65
1.22	17.31	0.66
1.52	12.99	0.66
1.83	10.20	0.67
2.13	8.26	0.68
2.44	6.83	0.70
2.74	5.74	0.73
3.05	4.88	0.76
3.35	4.18	0.80
3.66	3.61	0.84
3.96	3.14	0.89
4.27	2.75	0.95

4.57	2.42	1.01
4.88	2.14	1.08
5.18	1.90	1.15
5.49	1.69	1.23
5.79	1.51	1.32
6.10	1.36	1.41
6.40	1.22	1.51
6.71	1.11	1.61
7.01	1.00	1.72
7.32	0.91	1.84
7.63	0.83	1.96
7.94	0.76	2.09

3.8.7. Location of Application of Blast Load

The superstructure, particularly the deck slab, is the major structural part of a bridge that is mostly affected due to possible explosion on top of the bridge. The deck slab is a highly redundant member because of the presence of alternate load paths and integral connection with the girders through the shear keys. The loads, due to an explosion on top of the bridge, were distributed on the deck slab and ultimately applied as uniformly distributed loads along the centerline of the girders. Hence for the analysis purpose the blast phenomenon is considered above deck slab only.

In most cases, blast load is unpredictable like earthquake load. While earthquake may cause definable nature of horizontal and vertical movements, blast load has no definite direction of resulting movement. It can affect the structure from any direction at any angle of projection. Therefore, it is very difficult to characterize definite criteria for blast load direction. For the sake of simplicity, only the governing vertical or horizontal components of the inclined loads were applied on the members. All the loads were defined to act at the critical locations of the members. Downward loads were applied at mid-span of the slab-girder composite system to determine the maximum moment in the girder. The cases are represented in table 3.5.

3.8.8.Blast Load Cases

The amount of TNT explosive used herein is 226.8kg. This explosive loads were considered as an extreme event for which load factor used is 1.00. In addition to these blast loads, self weight of the structure was also considered with a factor of 1.5. The dead and live loads for an extreme event are presented in equation below 3.5. The vehicle live load is not considered in the analysis for simplicity and because of its effect is negligible compared to that of the blast load.

$$W_T = 1.5\ DL + 1.5\ LL + 1.00\ EV \qquad (3.5)$$

Where, W_T= Total load, DL = Dead load, LL= Live load, and EV = Extreme event load.

Following are some of the load cases taken for the analysis purpose.

Table 3.5.Various Load Cases.

Load Case	**Location**	**Member Affected**	**TNT equivalent explosive**	**Blast Set-backs**
Case 1	Over the bridge at mid-span.	Deck Slab, Girder.	226.8 kg	1m above the deck.
Case 2	Over the bridge above pier	Deck Slab, Girder, Pier.	226.8 kg	1 m above the deck.
Case 3	Over the bridge at mid-span.	Deck Slab, Girder.	226.8 kg	2 m above the deck.
Case 4	Over the bridge above pier	Deck Slab, Girder, Pier.	226.8 kg	2 m above the deck.

CHAPTER 4

RESULT AND DISCUSSION

Considering the above cases now next part we arrives is at the result and discussions. From the loading cases we have decided, following will be the obtained results which are seen one by one.

4.1. Case 1:

In this case the location of the blast is above the deck at the mid-span at 1m height. The TNT equivalent used here is 226.8 kg. Affected members mainly due to this case are deck slab and girder. The obtained result shows the deformed shapes of the slab, deflection at the nodal intervals, stress resultant, and bending nature. Following are the pressures that are calculated for case 1. As the blast waveform is spherical in nature hence for calculating the pressure for the sake of simplicity the pressure distribution is considered to be symmetric at an interval of 800mm.Due to the spherical nature of this wave-front some of the blast pressure intensities travels in upward direction too, and hence from the available literatures the pressure intensities acting on the structure, reduction factor of 50% can be applied.

Table 4.1.Pressure intensities for case 1.

Standoff Distance (m)	**Pressure Intensities (Mpa)**
4	22.52
3.2	18.016
2.4	13.512
1.6	9.008
0.8	4.501
0.0	1.465

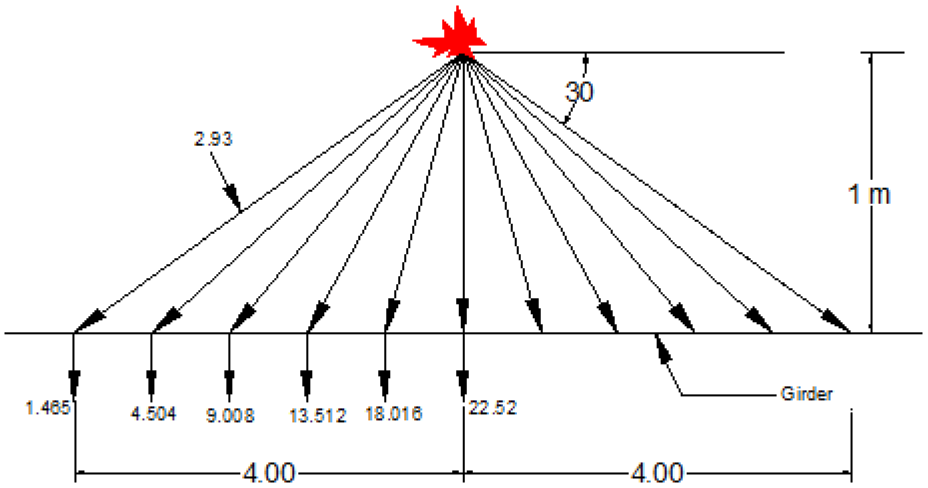


Figure. 4.1. Blast pressure distribution for Case 1.

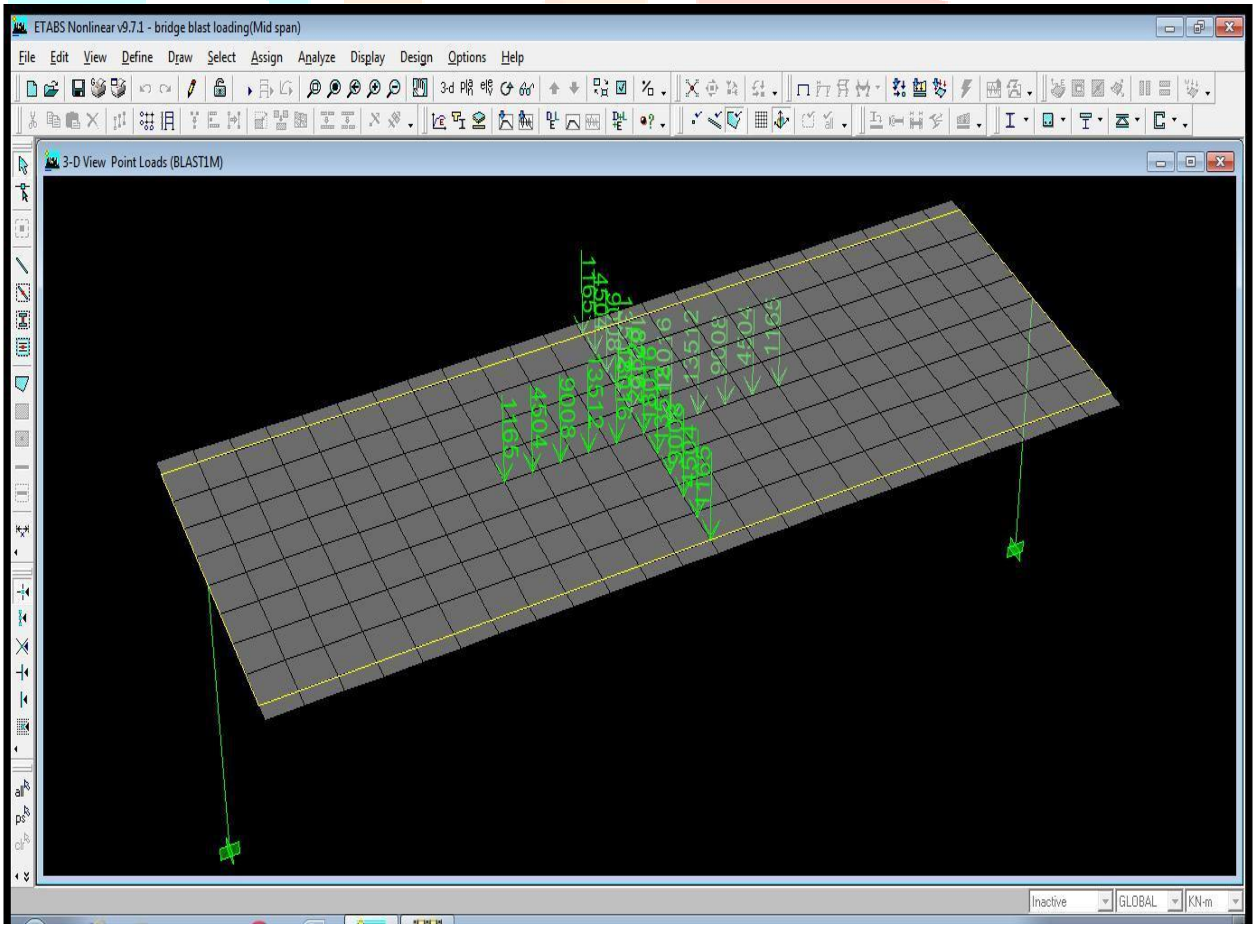
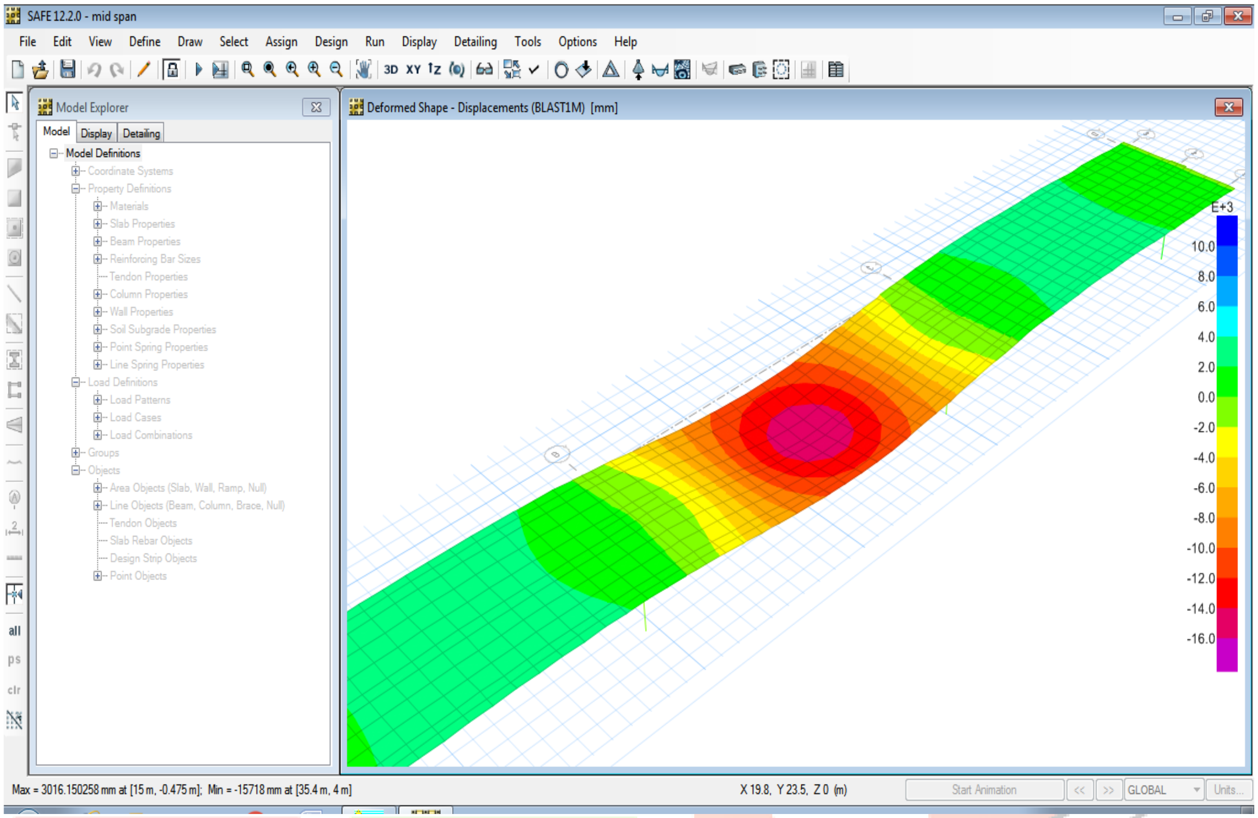
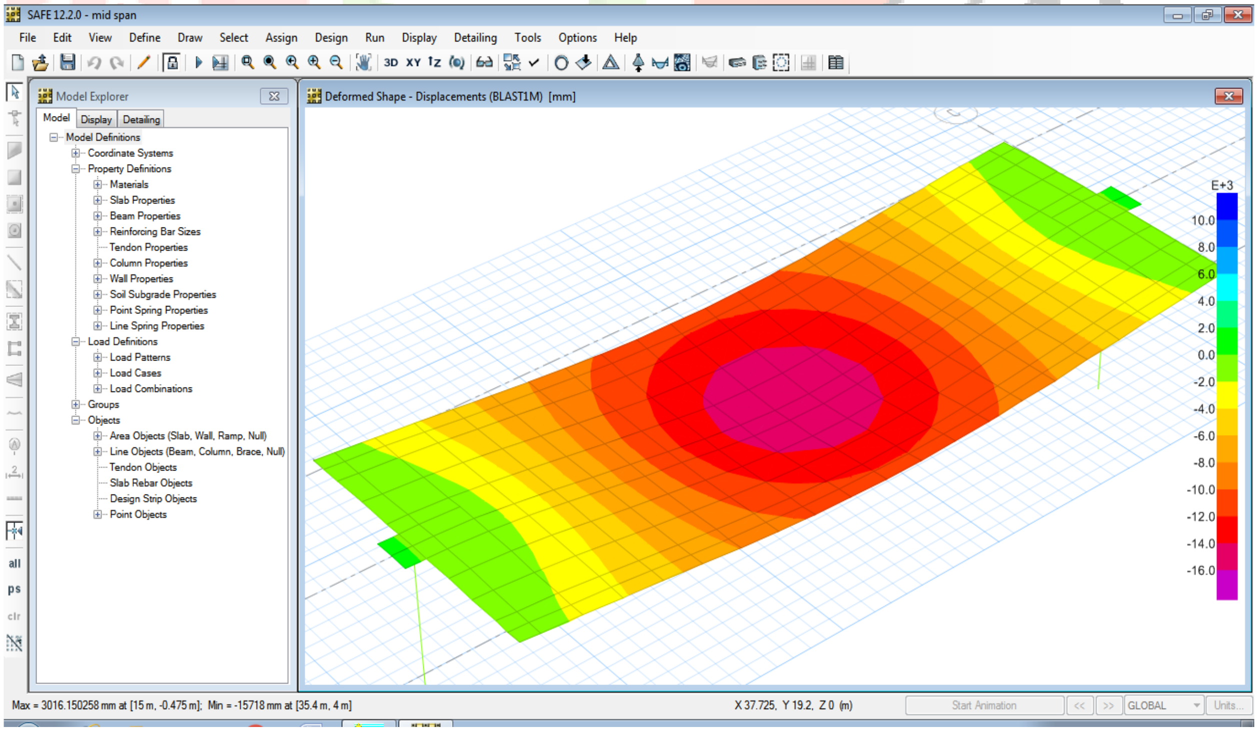


Figure. 4.2. Blast LoadDistribution for Case 1 in ETABS.



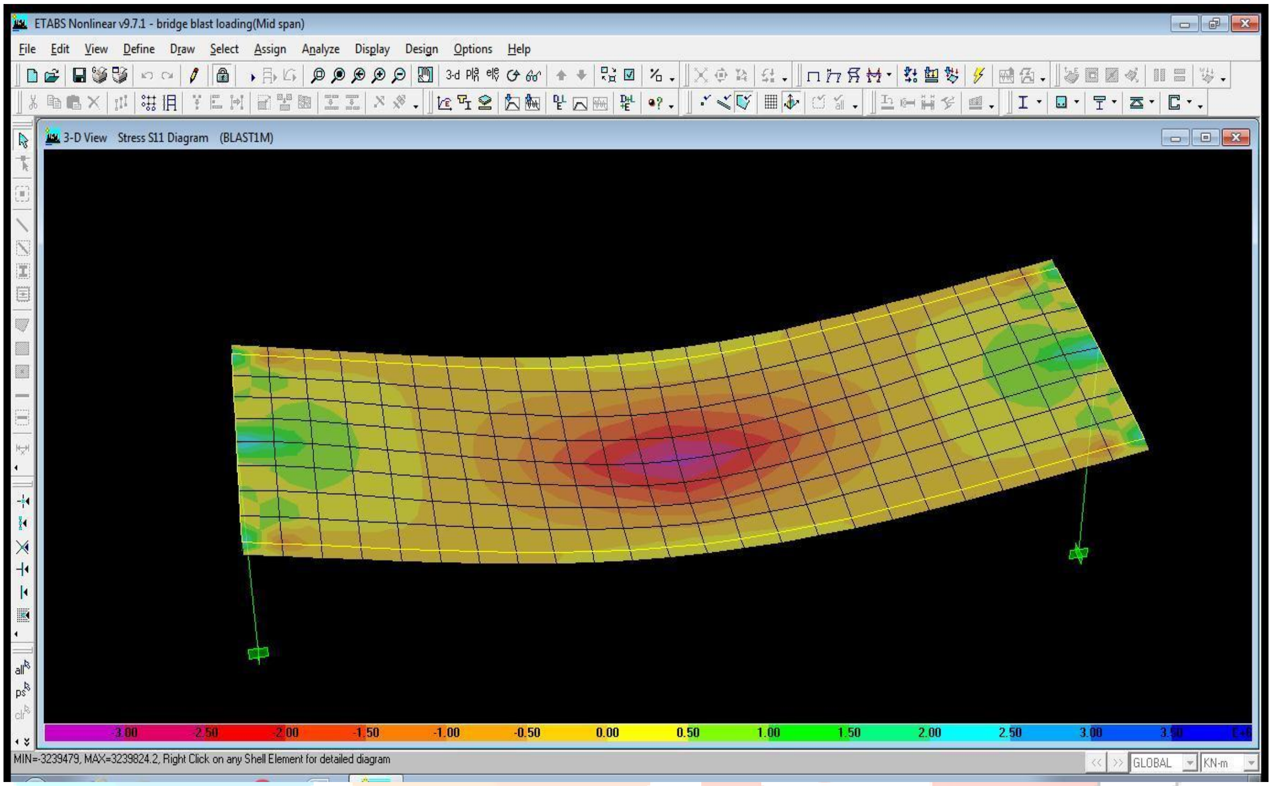
Max = 3016.150258 mm at [15 m, -0.475 m]; Min = -15718 mm at [35.4 m, 4 m]

Figure. 4.3. Deformation or Displacement of deck due Blast Load.



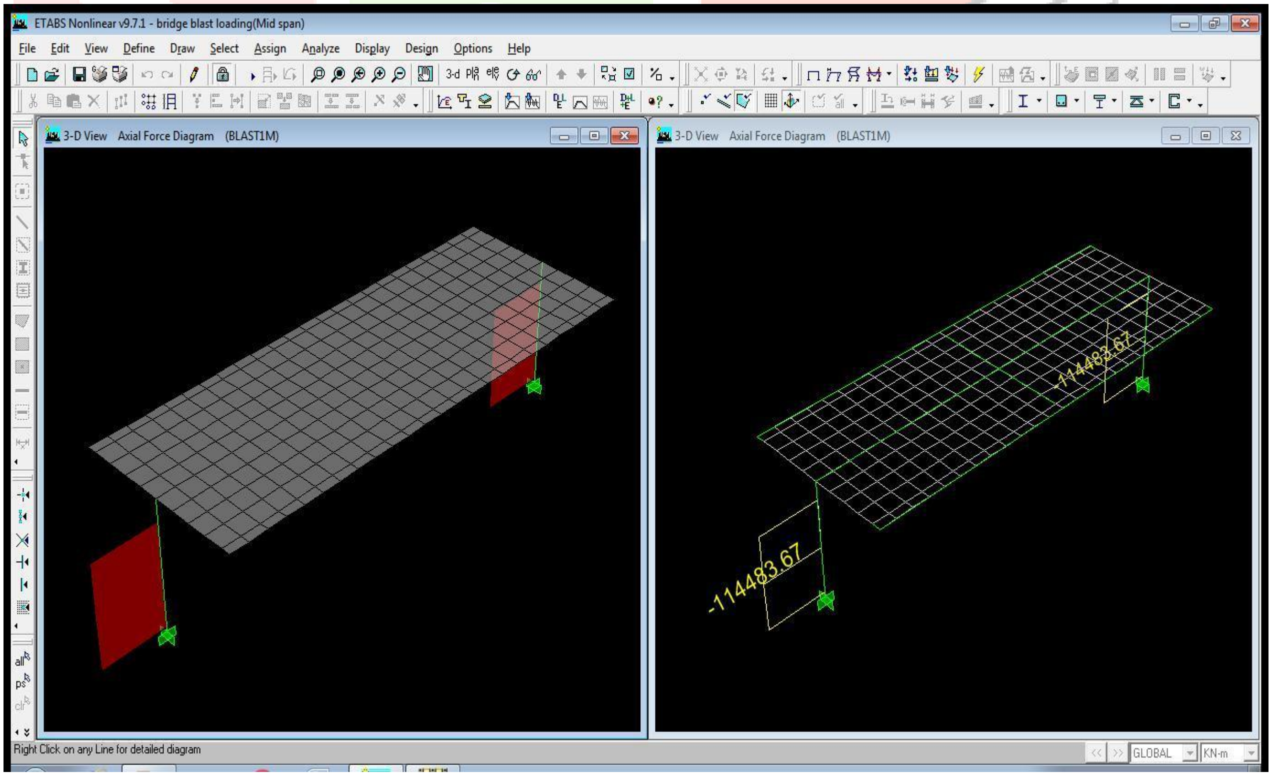
Max = 3016.150258 mm at [15 m, -0.475 m]; Min = -15718 mm at [35.4 m, 4 m]

Figure. 4.4. Displacement contour of deck due Blast Load.



MIN=-3239479, MAX=3239824.2, Right Click on any Shell Element for detailed diagram

Figure. 4.5. Stress contour of deck due Blast Load.



Right Click on any Line for detailed diagram

Figure. 4.6. Axial Loads on Column C2 and C3 due to Blast Load.

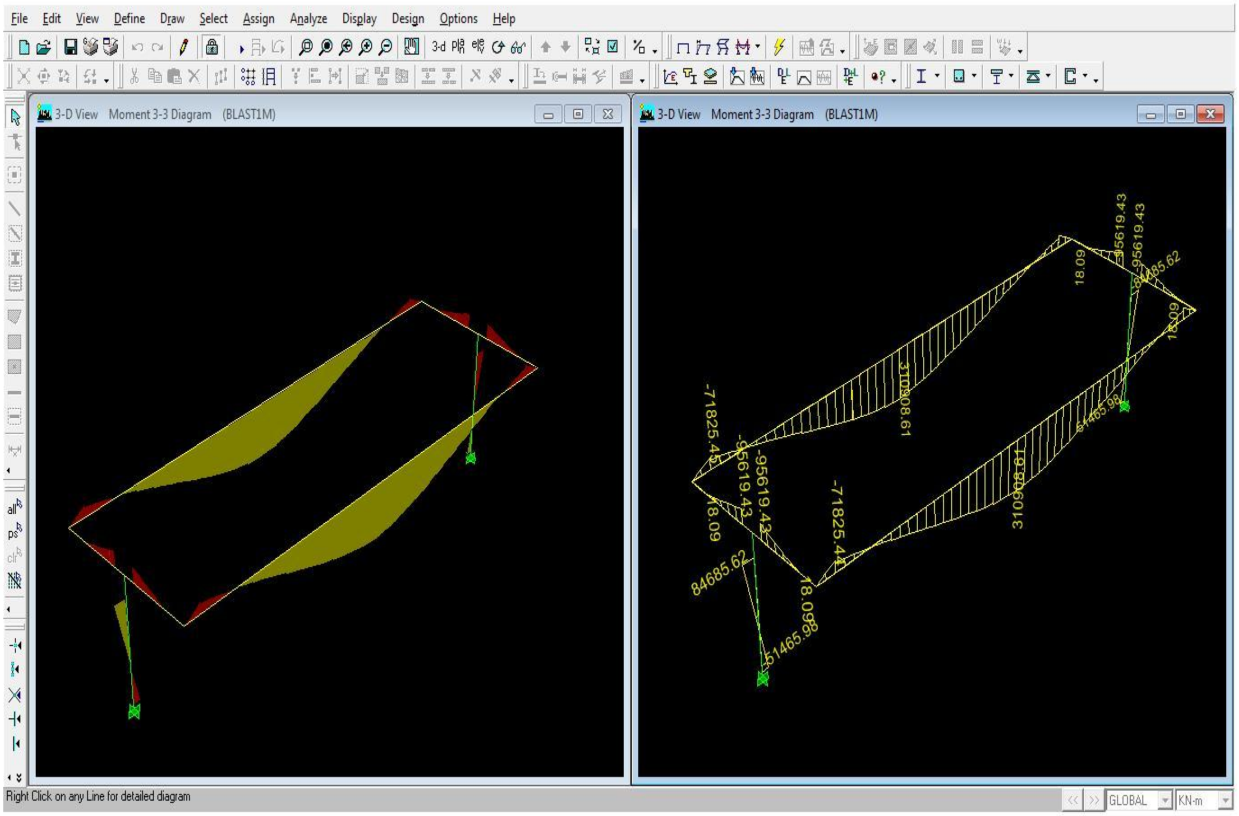


Figure. 4.7. Bending Moment diagram of girder due to Blast Load.

The columns of the bridge will experience axial loads due to application of blast load above the deck slab. And hence due to these loads on column they will experience an axial thrust in vertical direction which is shown in fig 4.6. It is also found that the deck slab and the girders subjected to the blast are most vulnerable parts of bridge. Since the load intensities are more heavy, stress strain displacement induced in the deck slab and girder are shown in figure 4.3. and figure. 4.4. to clearly understand the nature and behavior of the affected members due to application of blast loads. From figure 4.7.it is observed that the girder at the mid-span experiences the maximum tension and fails at such loads. The maximum deformation and the stresses are observed where directly blast load is directly perpendicular to the deck. From these figures there is no scope of such girder when subjected to such types of loads and hence it is evident that the model bridge underwent complete collapse to Case 1 loading requiring complete immediate replacement.

4.2. Case 2:

In this case the location of the blast is above the deck at the mid-span at 2m height. The TNT equivalent used here is 226.8 kg. Affected members mainly due to this case are deck slab and girder. The obtained result shows the deformed shapes of the slab, deflection at the nodal intervals, stress resultant and bending nature. Following are the pressures that are calculated for case 2.

Table 4.2.Pressure Intensities for case 2.

Standoff Distance (m)	Pressure Intensities (Mpa)
4	9.10
3.2	7.28
2.4	5.46
1.6	3.64
0.8	1.82
0.0	1.265

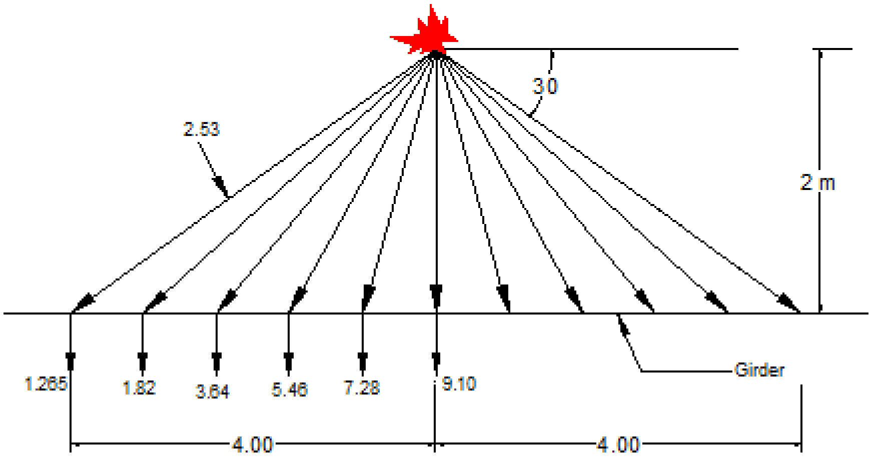


Figure. 4.8. Blast pressure distribution for Case 2.

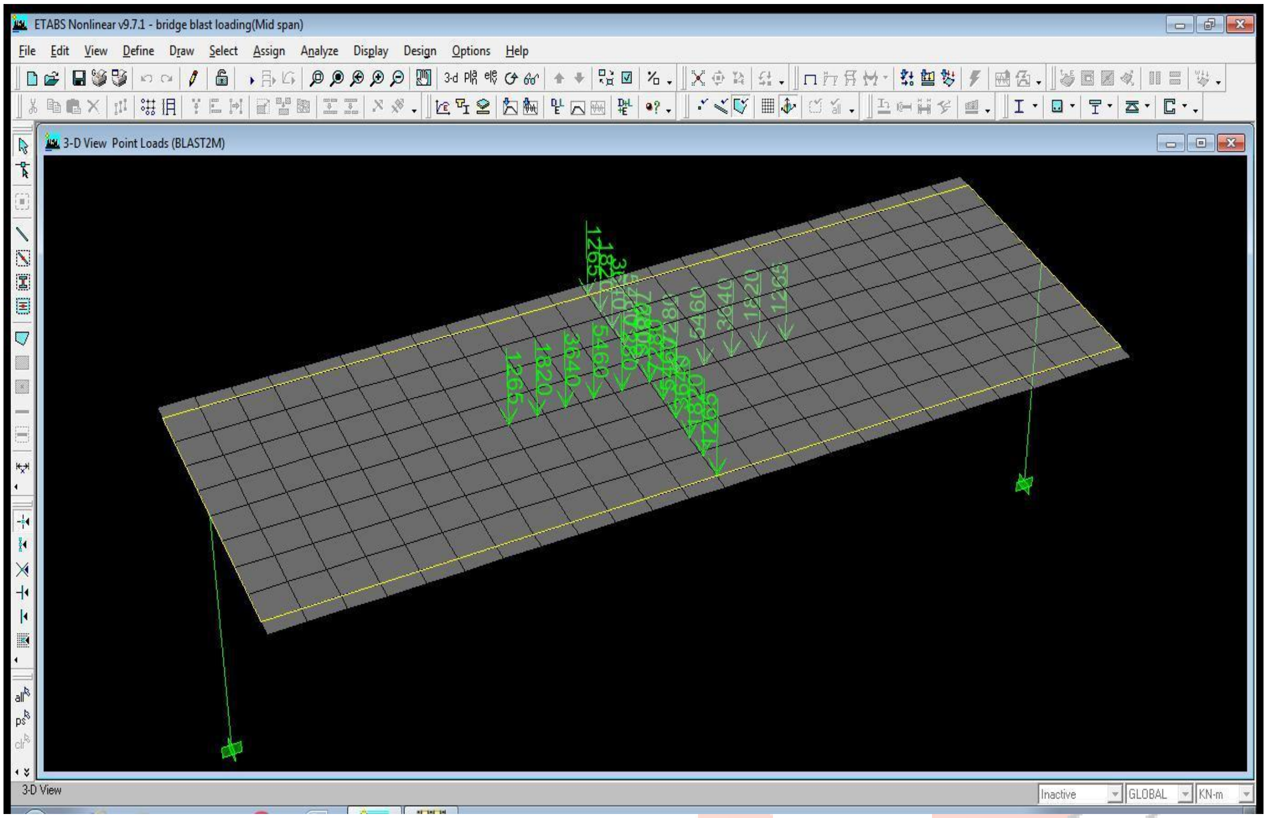
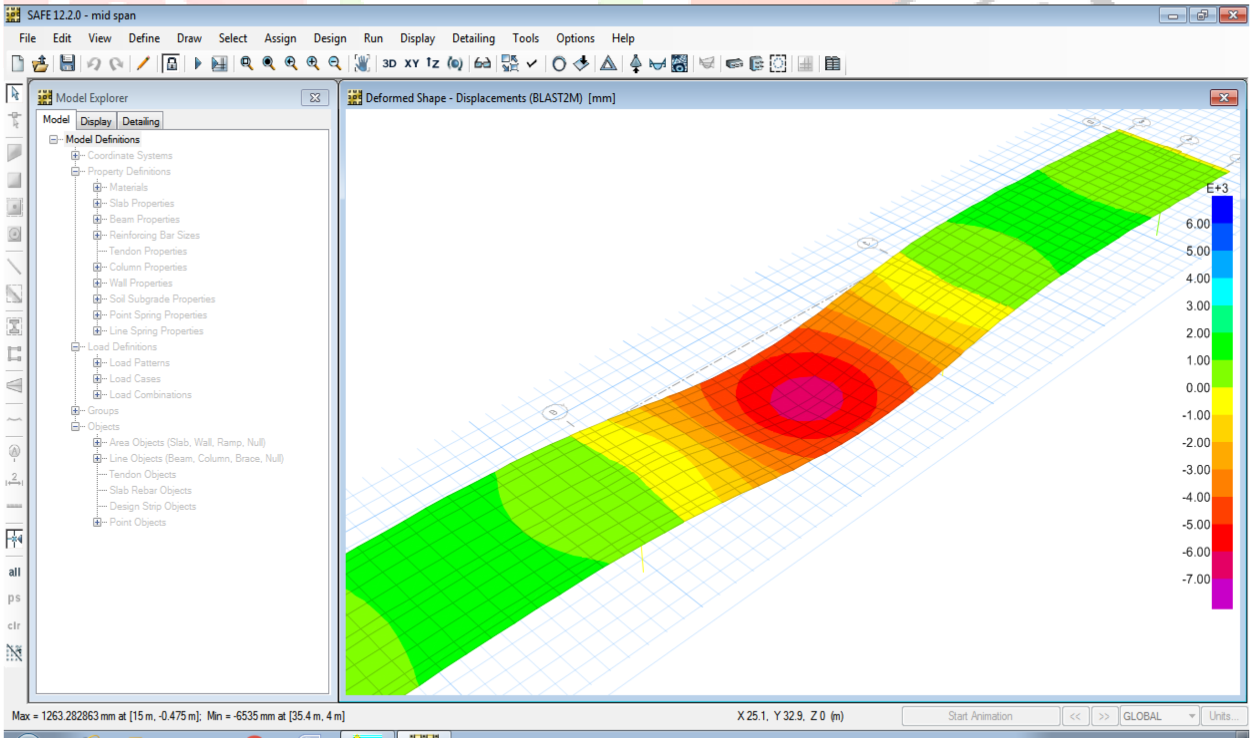
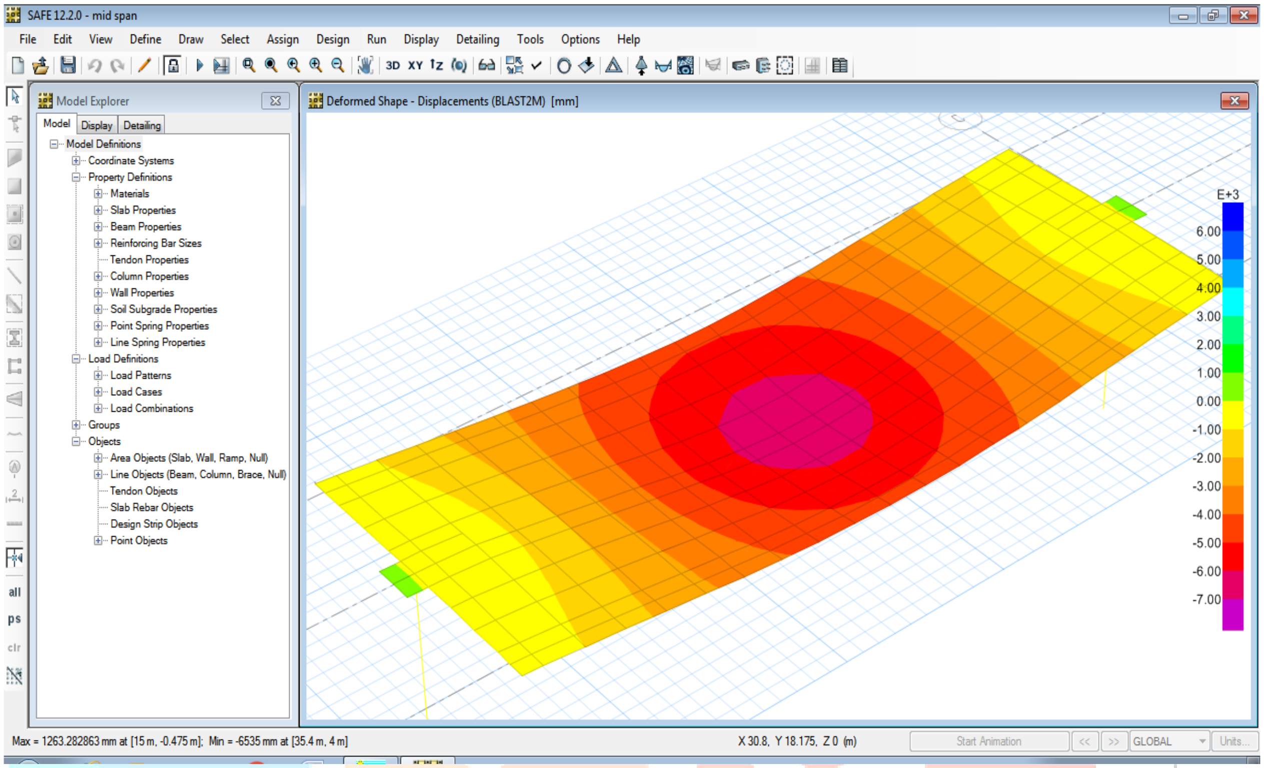


Figure. 4.9. Blast LoadDistribution for Case 2 in ETABS.



Max = 1263.282863 mm at [15 m, -0.475 m]; Min = -6535 mm at [35.4 m, 4 m]

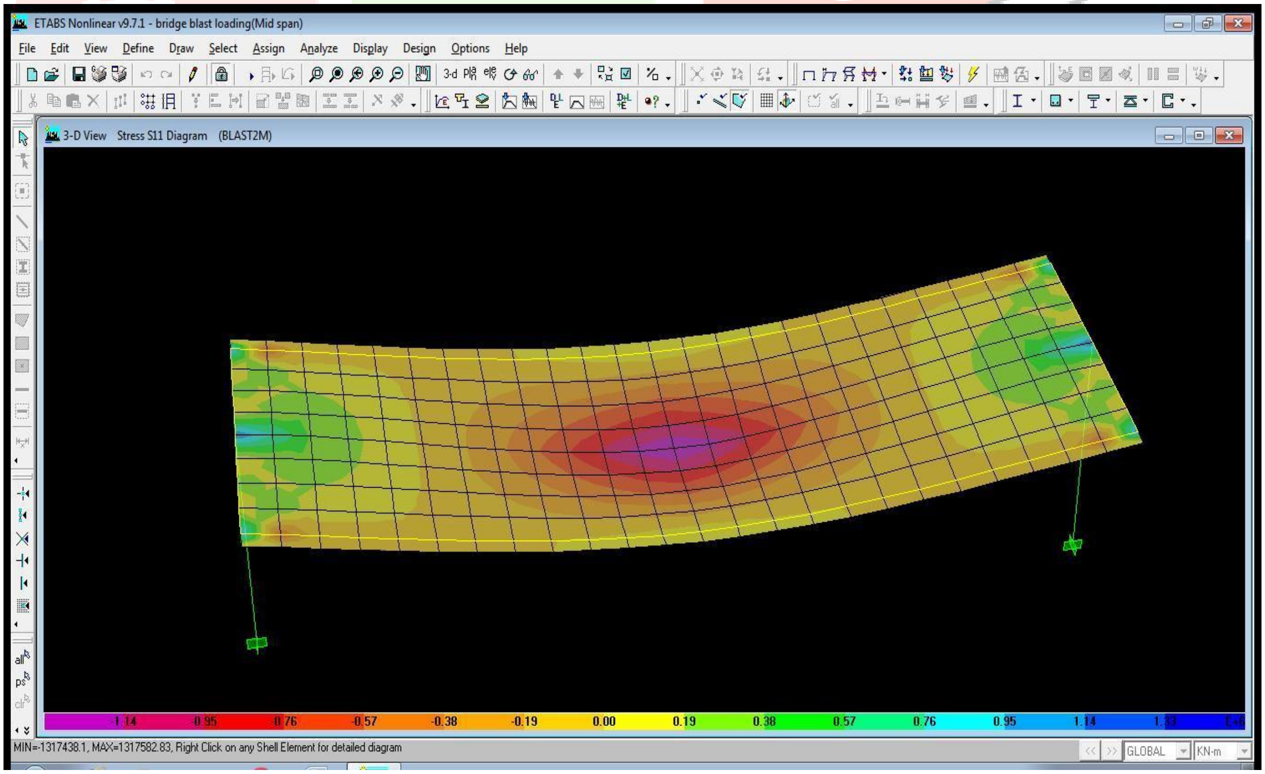
Figure. 4.10. Deformation or Displacement of deck due Blast Load.



Max = 1263.282863 mm at [15 m, -0.475 m]; Min = -6535 mm at [35.4 m, 4 m]

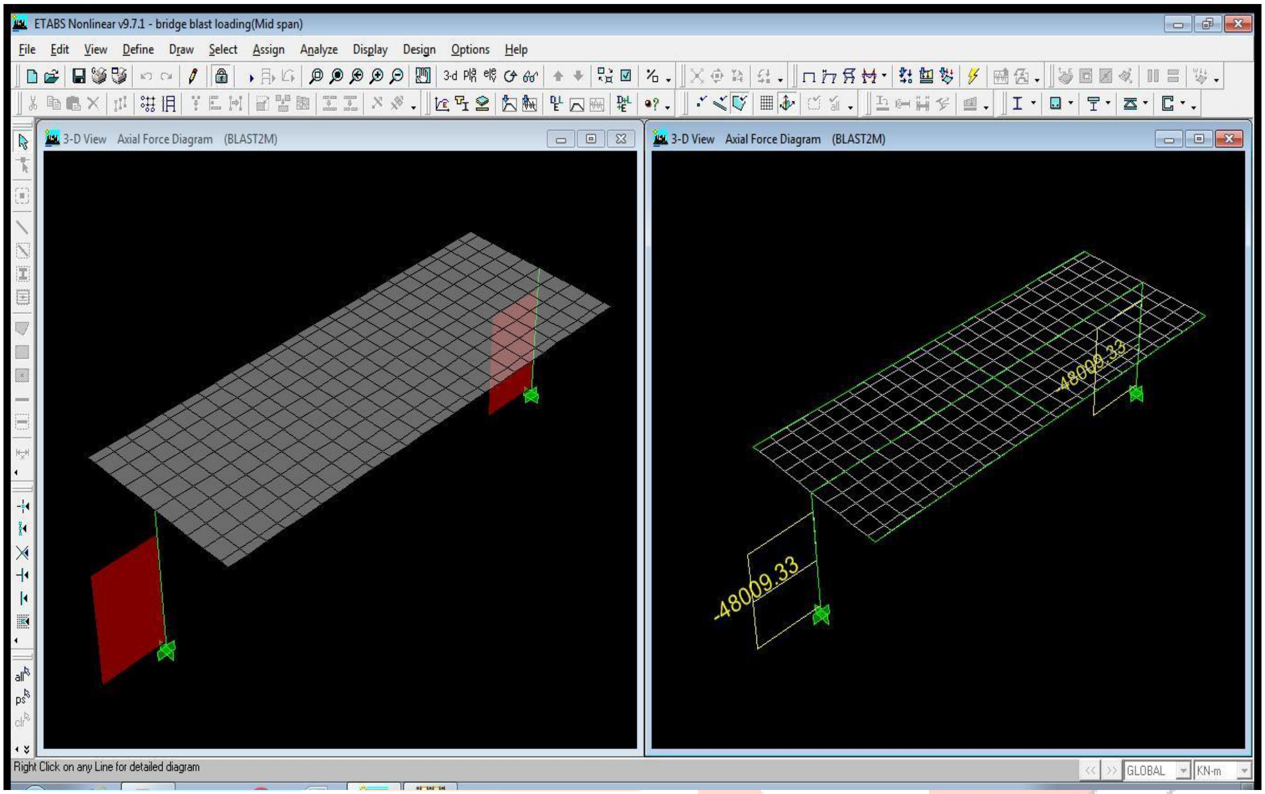
X 30.8, Y 18.175, Z 0 (m)

Figure. 4.11. Displacement contour of deck due Blast Load.



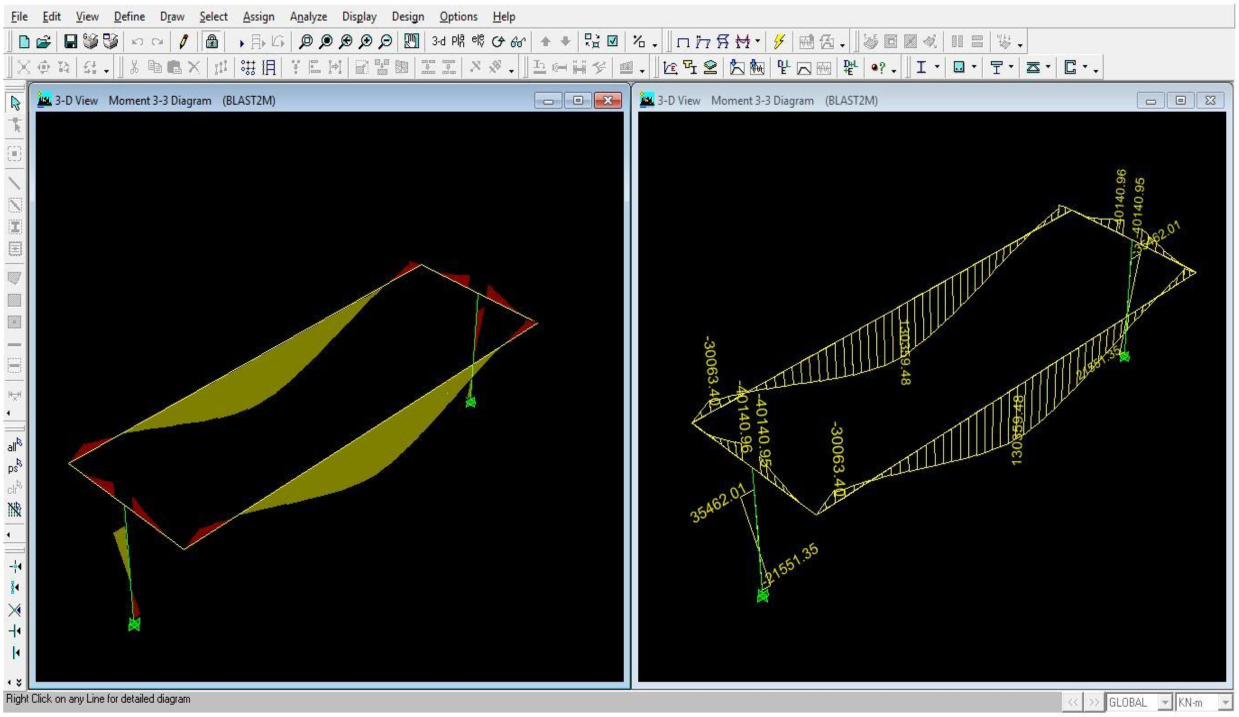
MIN=-1317438.1, MAX=1317582.83, Right Click on any Shell Element for detailed diagram

Figure. 4.12. Stress contour of deck due Blast Load.



Right Click on any Line for detailed diagram

Figure. 4.13. Axial Loads on Column C2 and C3 due to Blast Load.



Right Click on any Line for detailed diagram

Figure. 4.14. Bending Moment diagram of girder due to Blast Load.

Under this case it is seen that columns are affected in shear which experiences axial thrust less than that in case 1 shown in fig 4.12. It is also found that the deck slab and the girders subjected to the blast are most vulnerable parts of bridge. The stress strain displacement figures are shown in figure 4.6. and figure 4.8. to clearly understand the nature and behavior of the affected members due to application of blast loads. The maximum deformation and the stresses are observed where directly blast load is directly perpendicular to the deck. The bending nature of the beams is shown in fig 4.14. From these figures we can say that somewhat vulnerability is reduced when height of the blast explosion is increased. The observed deflections and deformation are seen to be reduced by almost 50% that in case 1 for an average height increment of 1m. Although vulnerability is reduced but from these figures there is no scope of such girder when subjected to such types of loads and hence it is evident that the model bridge underwent complete collapse to Case 2 loading requiring complete immediate replacement.

4.3. Case 3:

In this case the location of the blast is above the deck and above the pier at 1m height. The TNT equivalent used here is 226.8 kg. Affected members mainly due to this case are deck slab, girder and pier element. The obtained result shows the deformed shapes of the slab, deflection at the nodal intervals, stress resultant and bending nature. Following are the pressures that are calculated for case 3.

Table 4.3.Pressure intensities for case 3.

Standoff Distance (m)	Pressure Intensities (Mpa)
4	22.52
3.2	18.016
2.4	13.512
1.6	9.008
0.8	4.501
0.0	1.465

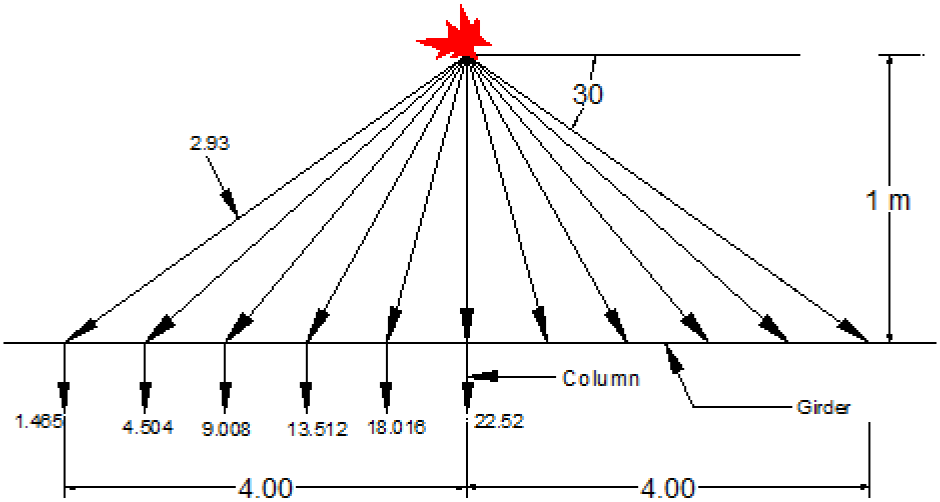


Figure. 4.15. Blast pressure distribution for Case 3.

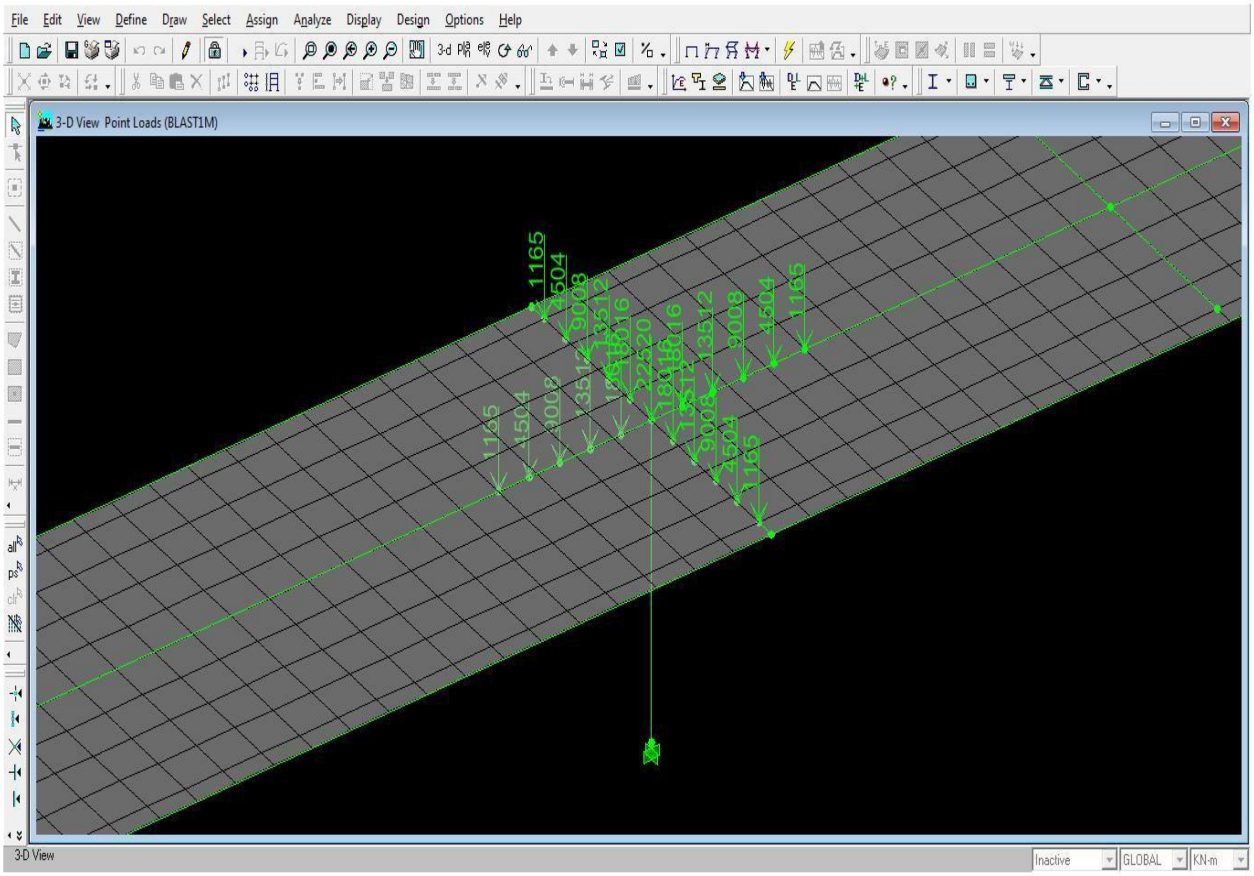


Figure. 4.16. Blast Load Distribution for Case 3 in ETABS.

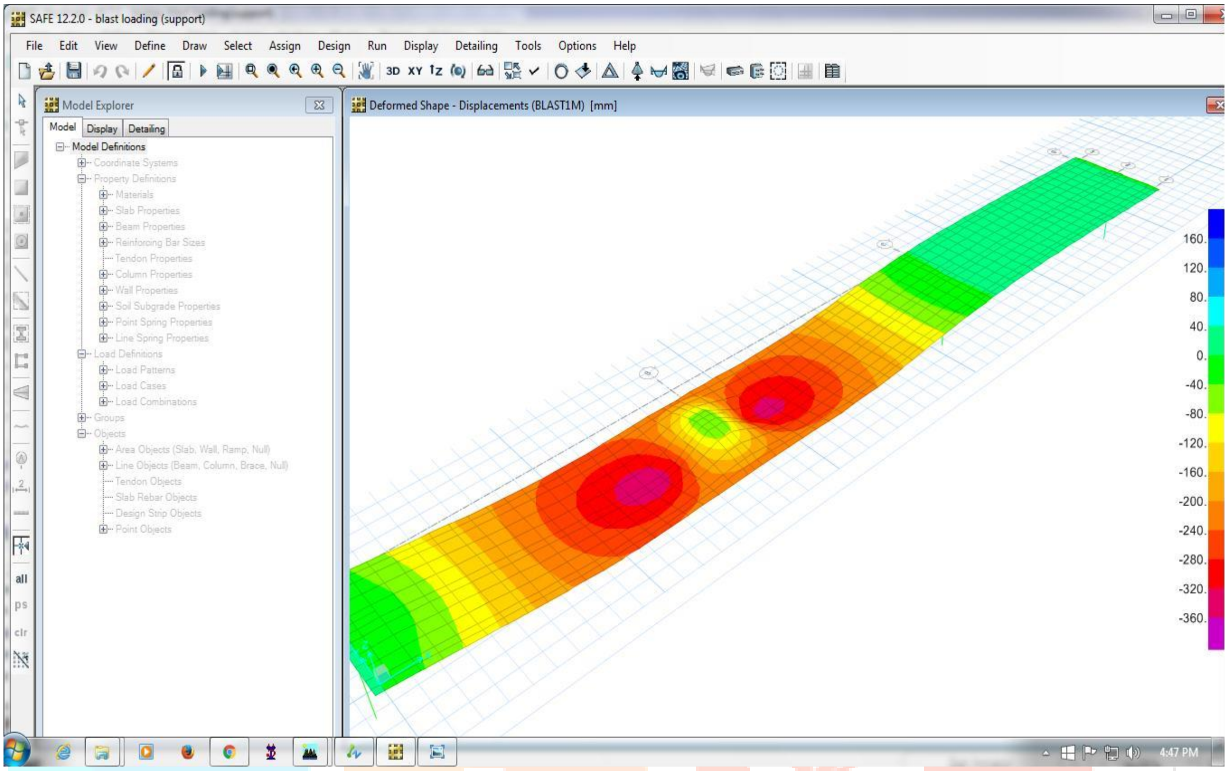


Figure. 4.17. Deformation or Displacement of deck due Blast Load.

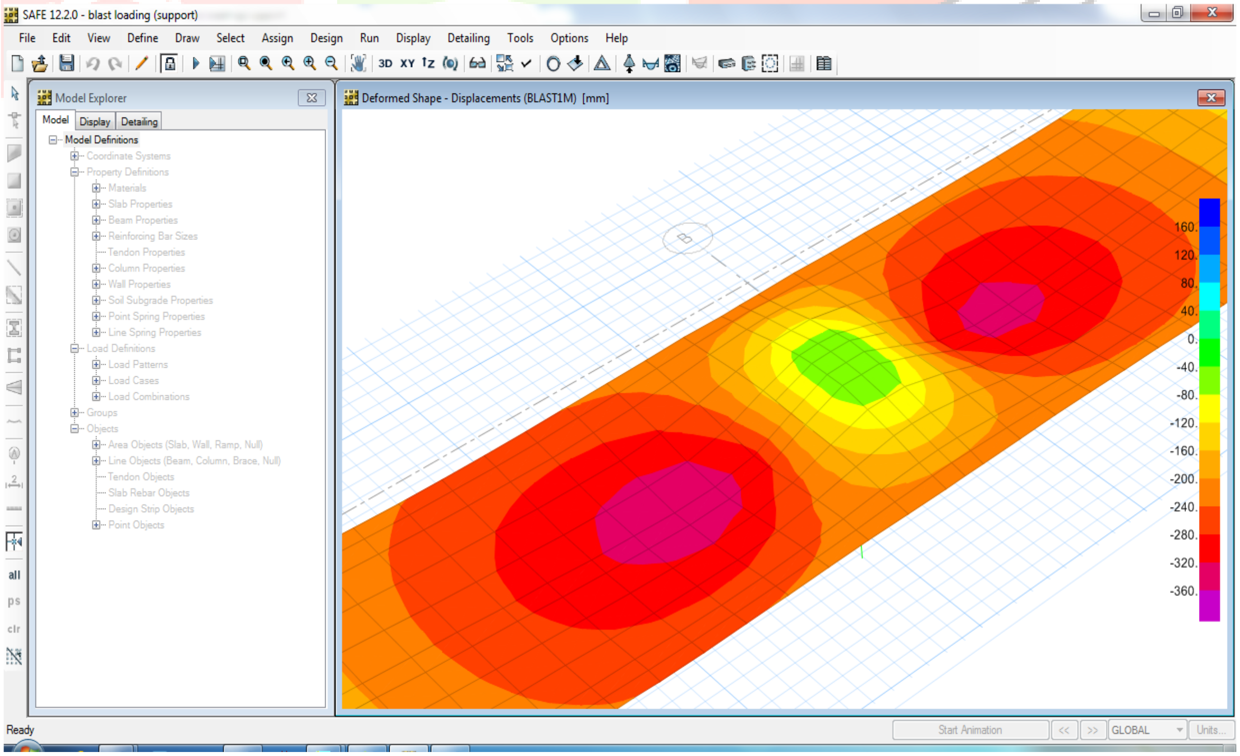


Figure. 4.18. Displacement contour of deck due Blast Load.

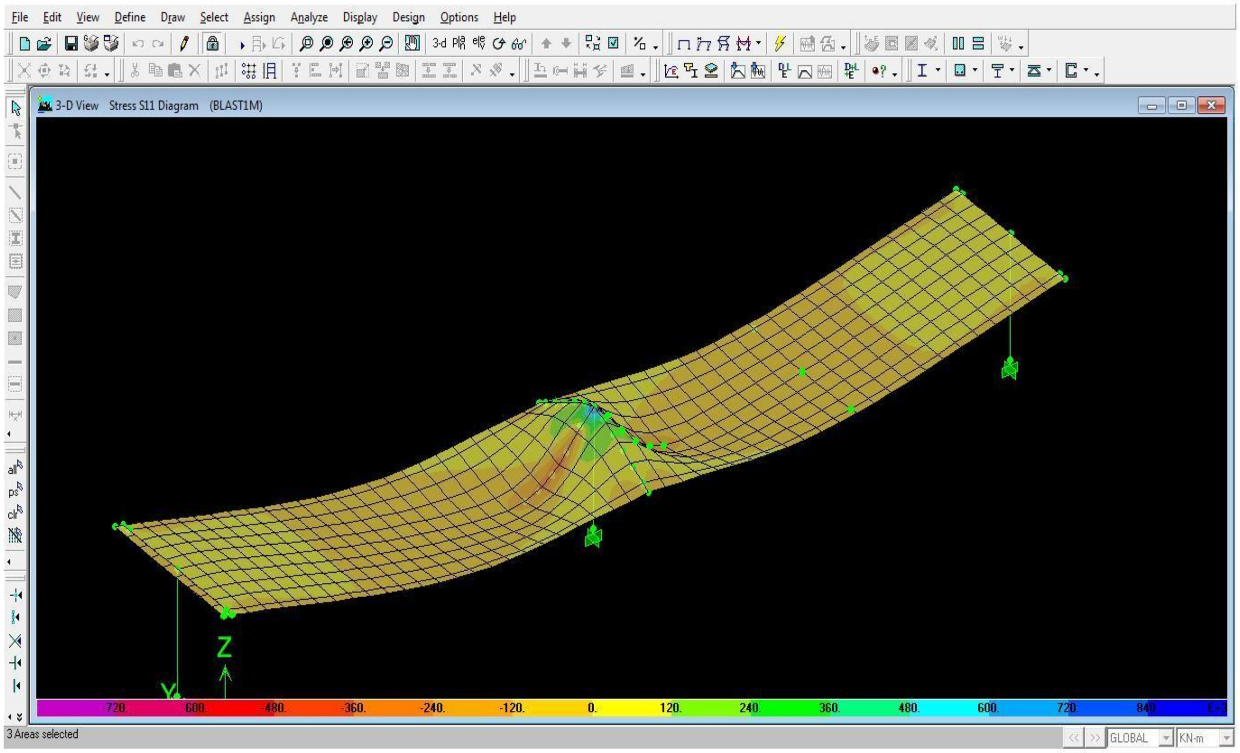


Figure. 4.19. Stress contour of deck due Blast Load.

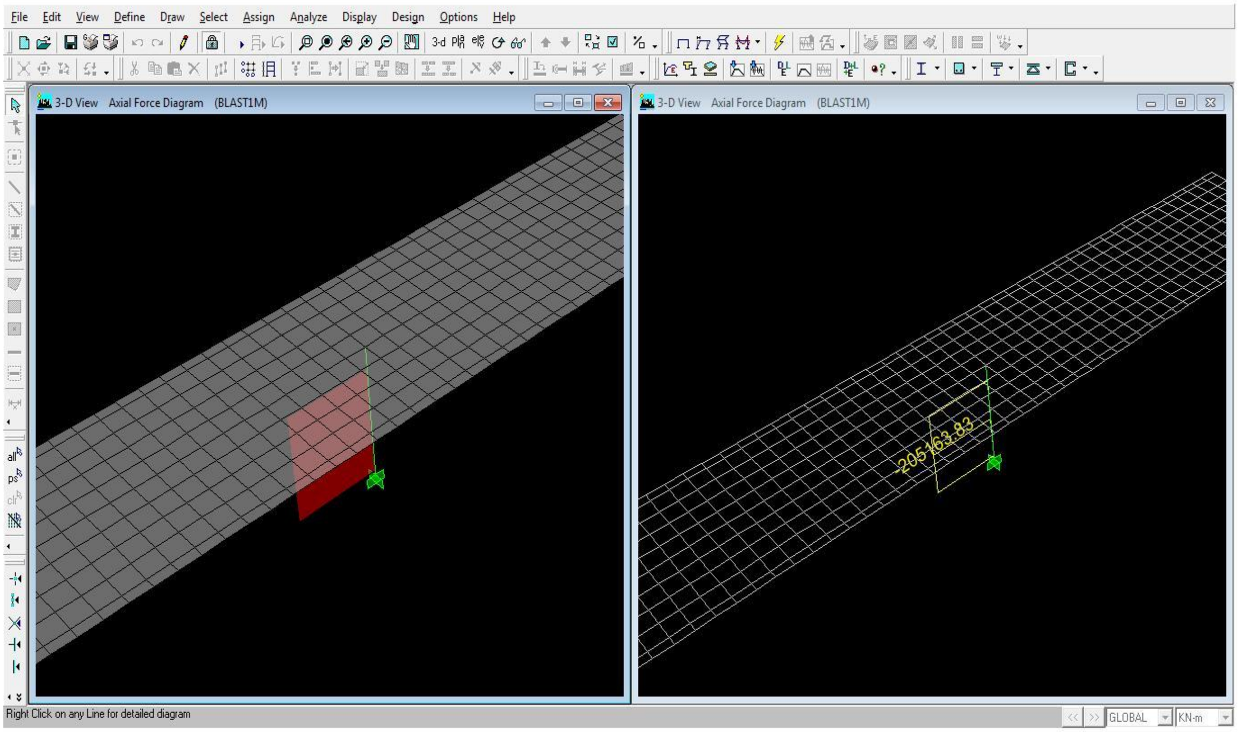


Figure. 4.20. Axial Loads on Column C2 due to Blast Load.

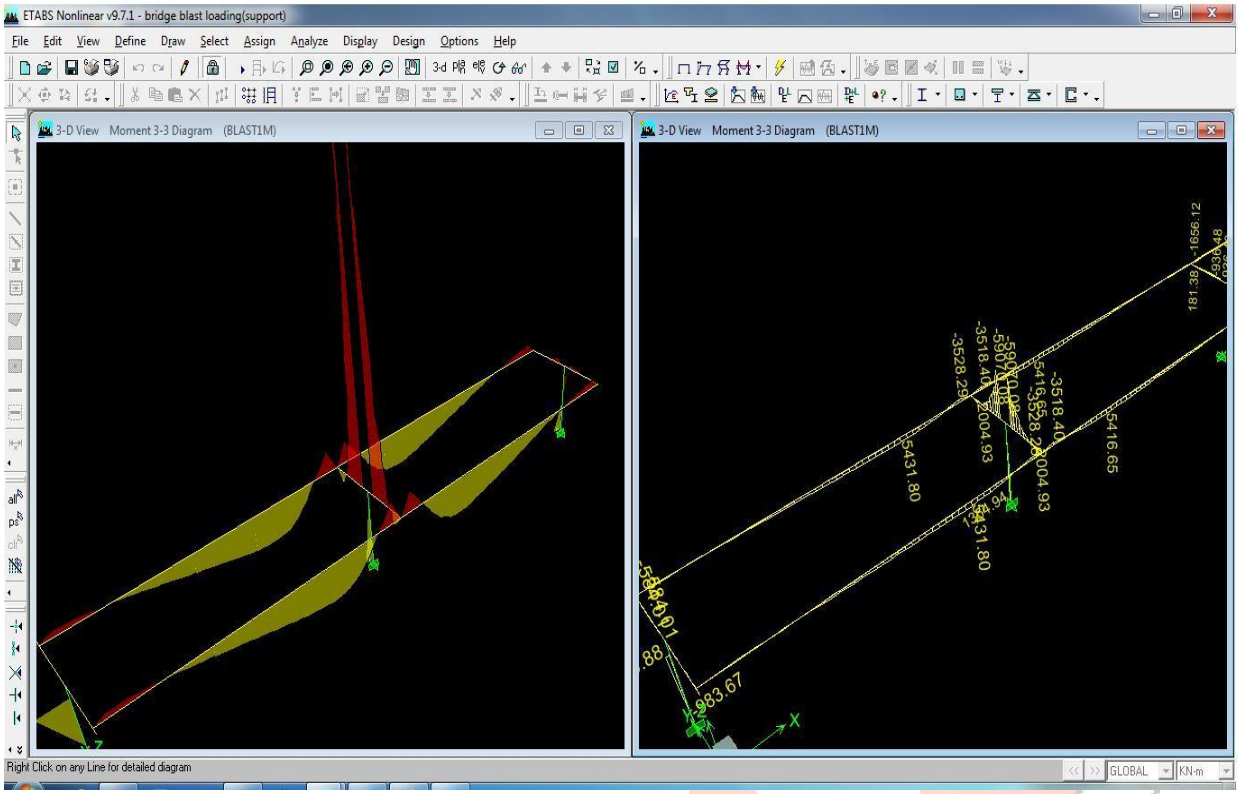


Figure. 4.21. Bending Moment diagram of girder due to Blast Load.

Under this case it is seen that when blast takes place above the pier and deck slab at the mid-span and does not experiences more deflection as compared to first two cases, while columns are affected in shear which experiences maximum axial thrust shown in fig 4.20. The stress strain displacements are shown in figure 4.17. and figure 4.19. to clearly understand the nature and behavior of the affected members due to application of blast loads. The maximum deformation and the stresses are observed where blast load is directly perpendicular to the deck. The bending nature of the beam is shown in figure 4.21. The negative moments are induced on the span above the column of bridge and hence the displacement pattern is observed to go upward figure 4.18. The girder fails due to lack of shear capacity under this case. The columns failed due to resulting moments and shears or axial forces. From these figures we can say that somewhat vulnerability is reduced when location of blast is changed and also it is evident that the model bridge for Case 3 loading requiring complete immediate repair or replacement.

4.4. Case 4:

In this case the location of the blast is above the deck and above the pier at 2m height. The TNT equivalent used here is 226.8 kg. Affected members mainly due to this case are deck slab and girder. The obtained result shows the deformed shapes of the slab, deflection at the nodal intervals, stress resultant and bending nature. Following are the pressures that are calculated for case 4.

Table 4.4.Pressure Intensities for case 4.

Standoff Distance (m)	Pressure Intensities (Mpa)
4	9.10
3.2	7.28
2.4	5.46
1.6	3.64
0.8	1.82
0.0	1.265

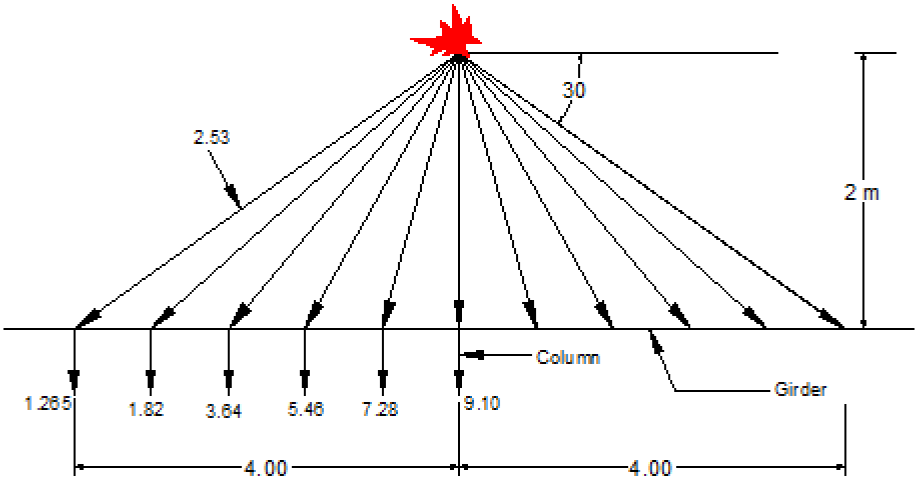


Figure. 4.22. Blast pressure distribution for Case 4.

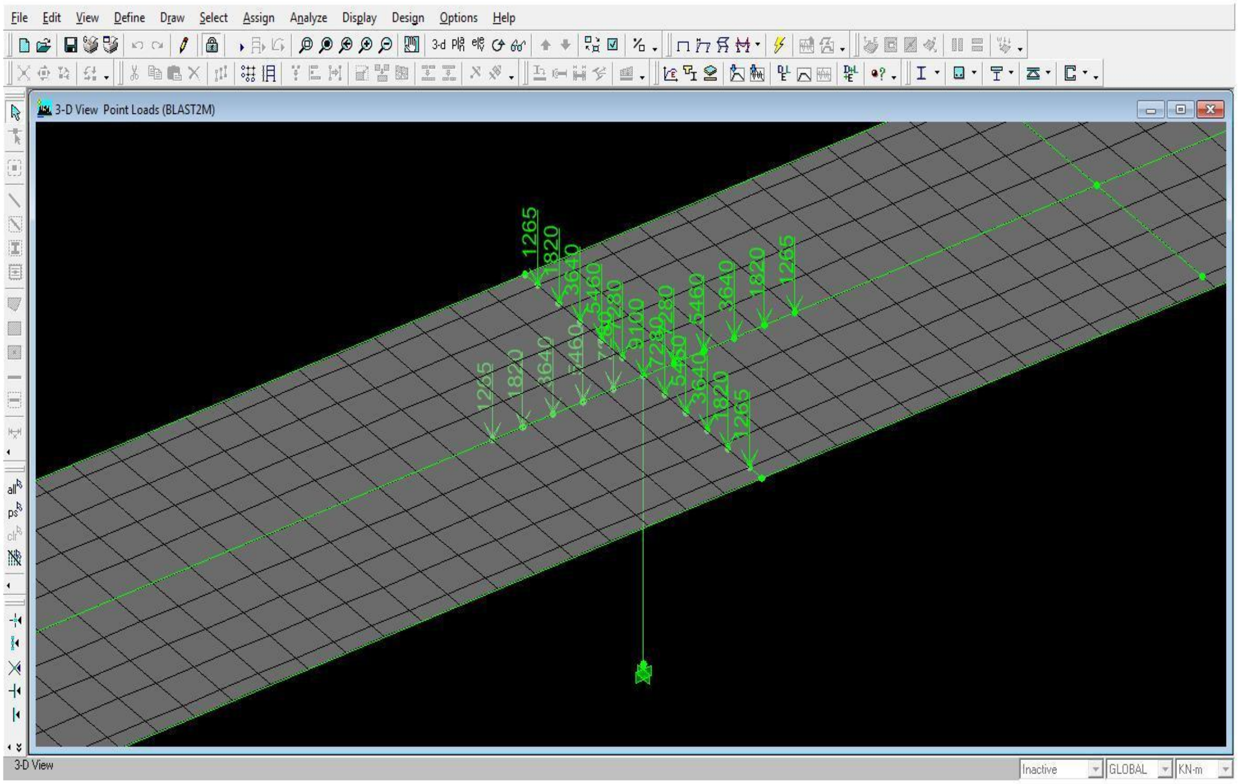


Figure. 4.23. Blast LoadDistribution for Case 4 in ETABS.

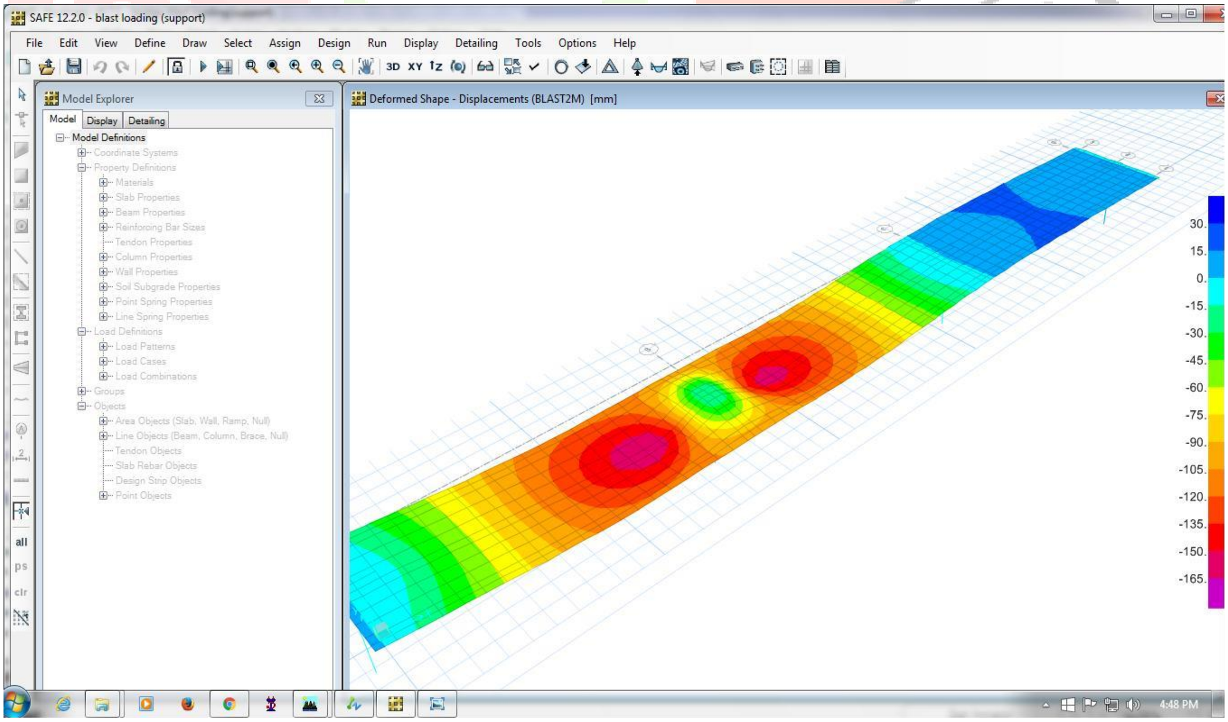


Figure. 4.24. Deformation or Displacement of deck due Blast Load.

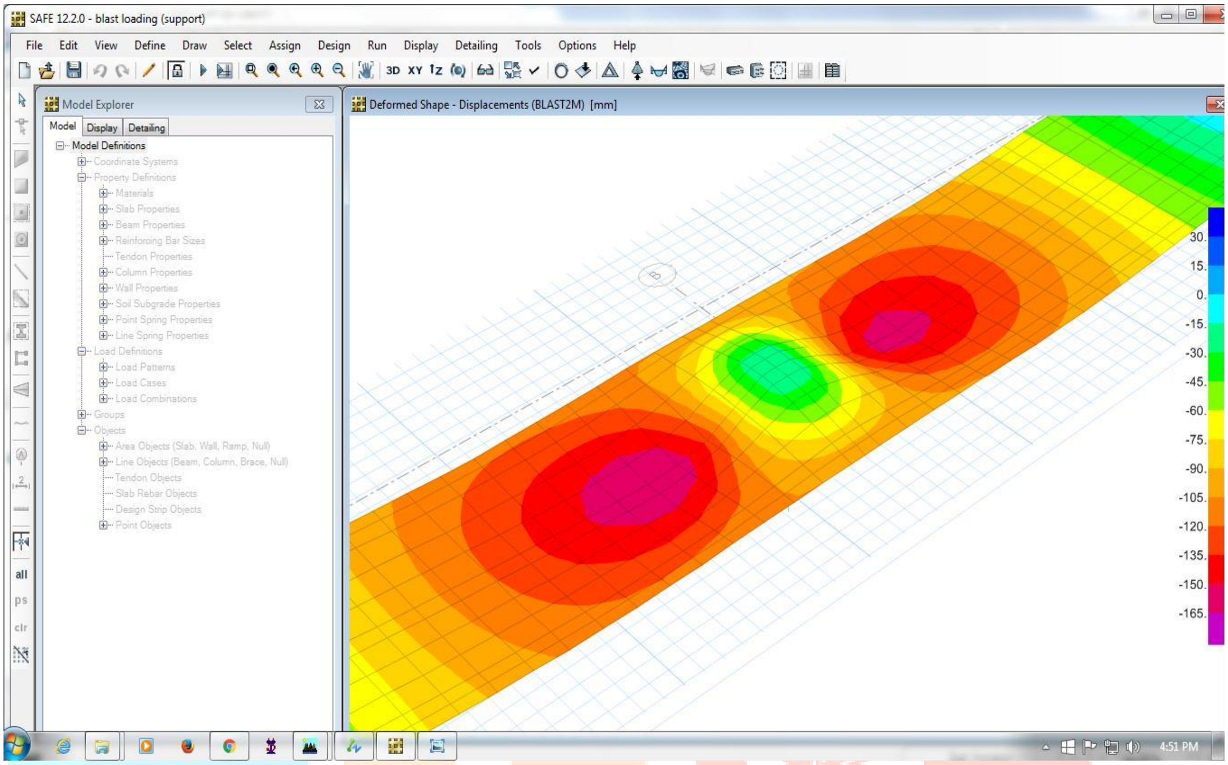


Figure. 4.25. Displacement contour of deck due Blast Load.

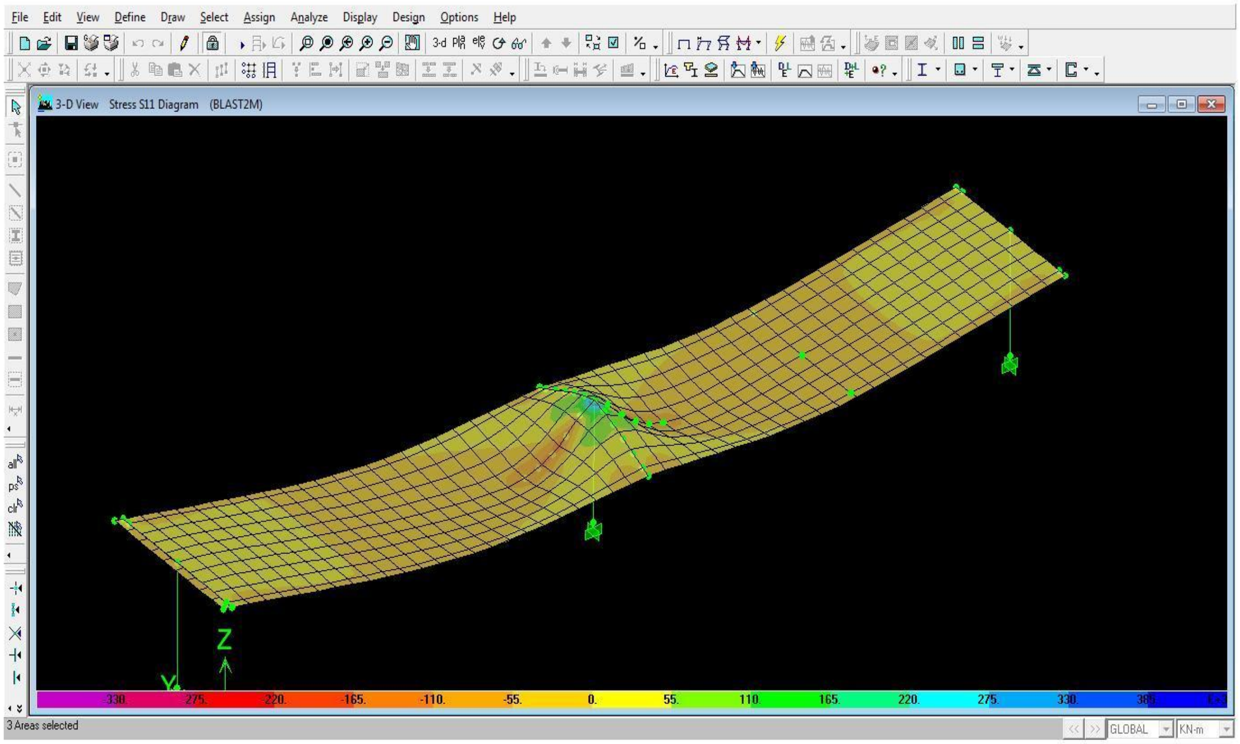
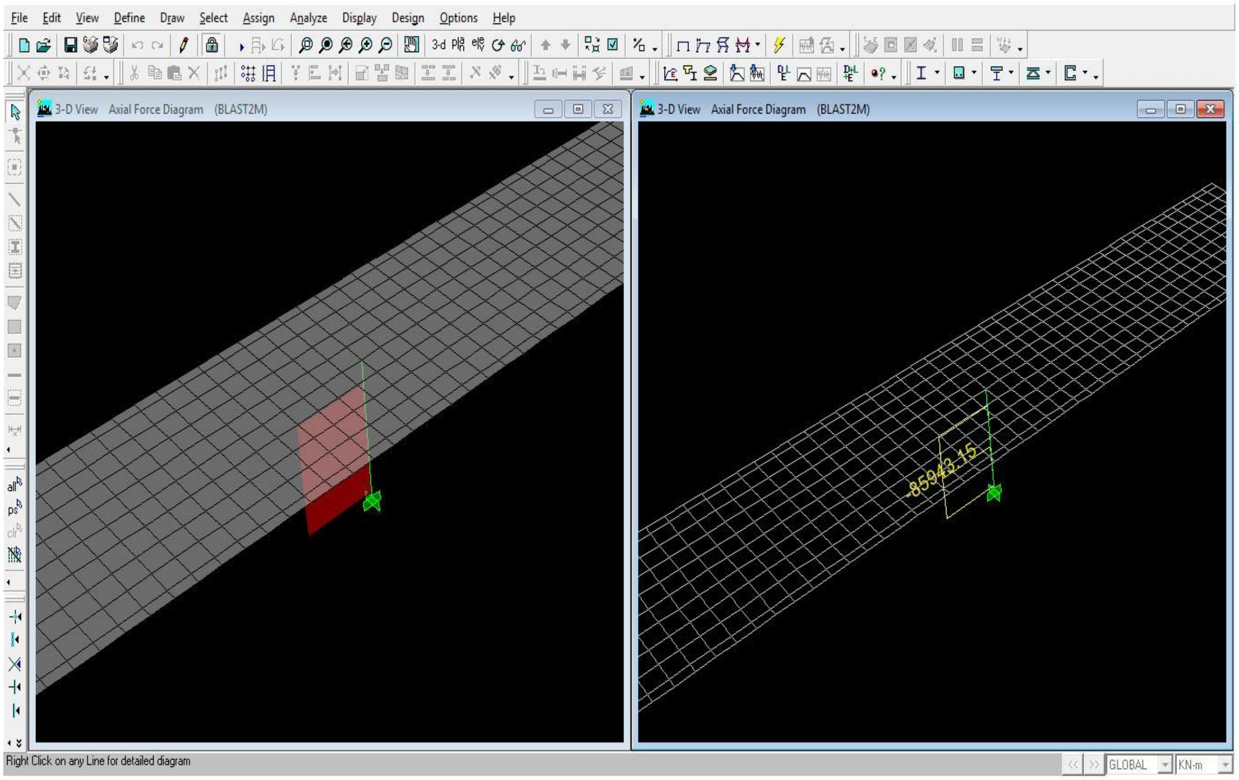
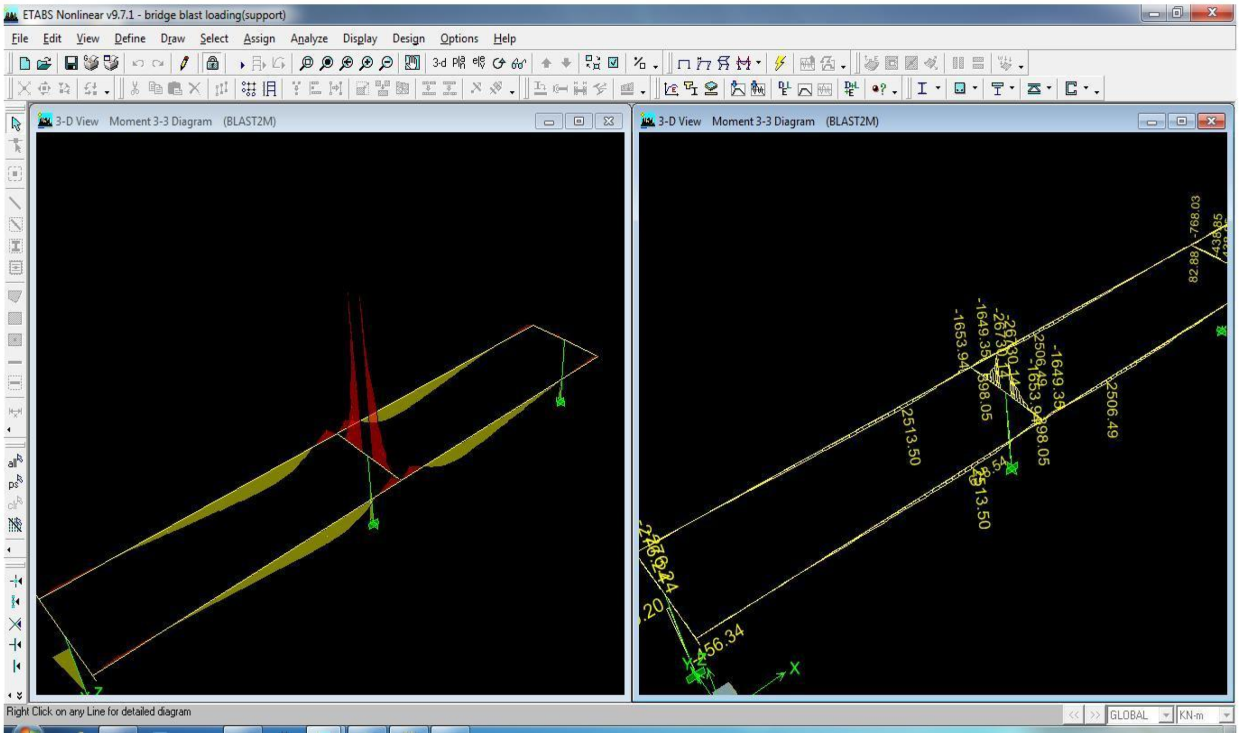


Figure. 4.26. Stress contour of deck due Blast Load.



Right Click on any Line for detailed diagram

Figure. 4.27. Axial Loads on Column C2 due to Blast Load.



Right Click on any Line for detailed diagram

Figure. 4.28. Bending Moment diagram of girder due to Blast Load.

Under this case it is seen that when blast takes place above the pier and deck slab at the mid-span does not experiences more deflection as compared to first two cases, while columns are affected in shear which experiences maximum axial thrust shown in figure 4.27. The stress strain displacements are shown in figure 4.24. and figure 4.26. to clearly understand the nature and behavior of the affected members due to application of blast loads. The maximum deformation and the stresses are observed where blast load is directly perpendicular to the deck. The bending nature of the beam is shown in figure 4.28. The negative moments are induced on the span above the column of bridge and hence the displacement pattern is observed to go upward. The girder fails due to lack of shear capacity under this case. The columns failed due to resulting moments and shears or axial forces. From these figures we can say that somewhat vulnerability is reduced when location of blast and height of is changed and also it is evident that the model bridge for Case 4 loading requiring complete immediate repair or replacement.

4.5. Stress Comparison from 4 cases:

From the obtained figure below it is seen that the stresses are reduced as the distance of the blast propagates. Looking at the four cases it is evident that stresses are less for the 4th case as compared to other. So we can predict that if the blast location is above the pier the damage caused to the bridge will be less, but still the members which are affected in the event requires an immediate replacement.

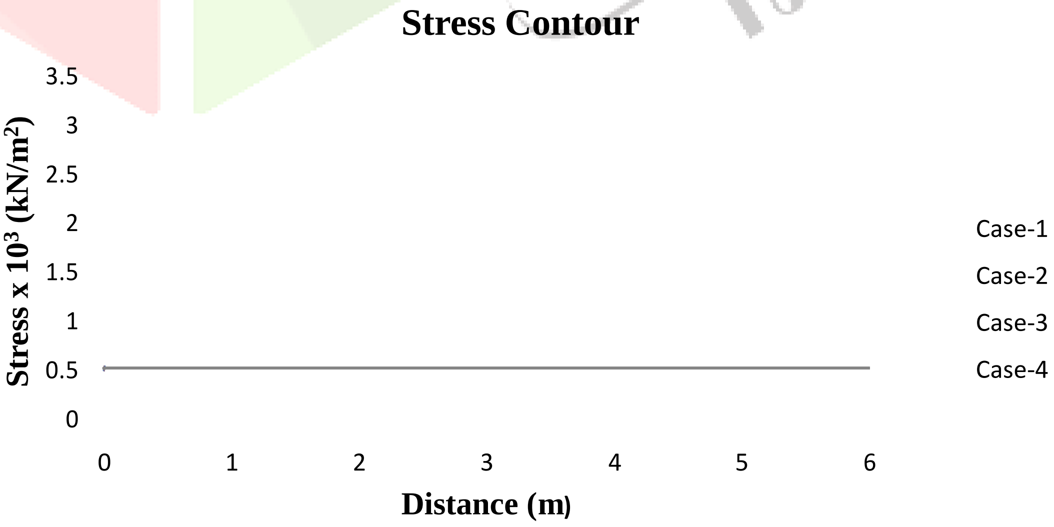


Figure.4.29. Comparison of stresses of 4 cases

CHAPTER 5

CONCLUSION

5.1. Conclusion

Based on this study, following conclusions can be made.

1) From the obtained results we can say that blast loads are the most vulnerable attacks of very high intense pressures and hence structure undergoes progressive collapse under these loads (refer table 3.4 and figure 3.10)
2) It was found from the analytical study that the RCC girder bridge will fail to probable blast load generated by an explosion of 226.8kg of TNT when applied over the bridge at mid-span and above the column.
3) In case of the blast occurring on the pier or column, the vulnerability of blast is reduced and hence some parts of the bridge seems to survive.
4) Bridge damage is more when blast occurs at the mid-span. The structure completely fails in this case and hence immediate replacement is needed.(refer figure 4.29)
5) Blast loads were determined as a record of pressure-time history with the parameters calculated as per available literatures (refer table 3.4).
6) Basic aim behind the analysis was to determine the structural behavior of the structural members subjected to blast loads and hence take necessary precautions and changes in structure to sustain it.
7) It illustrates that the characteristic of damage effect of a blast load to the whole bridge is limited to destruction zone near the blast, which corresponds to the general law of explosion.

5.2. Future Scope of Study

Although the detailed study regarding blast analysis is done in this work, the study presented here can lay a foundation for further detailed study regarding analyses of blast effects on bridges. Following are some future needs that can be studied in this area.

1) In this study we have used 4 cases for the analysis. For further work these cases can be changed considering different intensities of blast explosives.
2) Further study can be also done by changing the location of the blast event. The location can be considered below the deck with variable conditions of blast intensities.
3) Structural failure and its response for different components parts of bridge can be simulated.
4) To protect bridges from the act of terrorist explosion, blast resistant bridge design should be developed and adopted by the applicable code and practices.

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