To Study The Effect of Blast Loading on Bridge Structure

Mr. Sushant J. Jawak[1], Prof. Vaibhav V. Shelar[2]
[1, 2] Department of Civil Engineering
[1, 2] Trinity college of Engg . and Research, Pune, Maharashtra,India.

Abstract- *There has been increased awareness about safety of highway bridges from intentional/unintentional blast loads. This report focuses on the investigation of behavior of various bridge components during blast loads through a high fidelity finite element model of a typical highway bridge. Computer programs, such as E-Tab offer detonation simulation capabilities to propagate blast loads through air medium. 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. Simulation results show that seismic capacities and blast load effects are strongly correlated. Better seismic capacity directly implies better blast load resistance.*

Keywords- TNT, E-Tab, Blast Loading, RDX.

I. INTRODUCTION

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[18].

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.

II. ANALYTICAL ANALYSIS

1. 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.

2. Modeling of Bridge

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:

Material	**Element**	***fc*(Mpa)**	**Poisson's ratio**	***Wc*(kg/m^2)**	***Ec*(MPa)**
Material 1	Girder, Deck slab,	40	0.2	2400	31,650

Table 1. Mechanical Properties

Where,
fc = 28 days compressive strength of concrete
Wc= Unit weight of concrete.
Ec = 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).

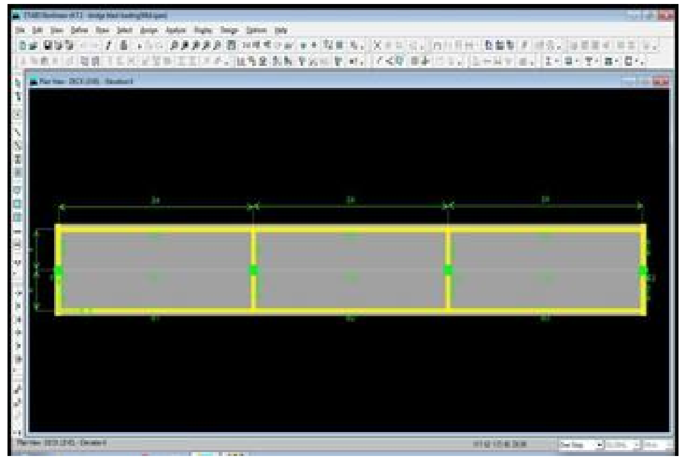

Figure 1. Plan of Modeled bridge.

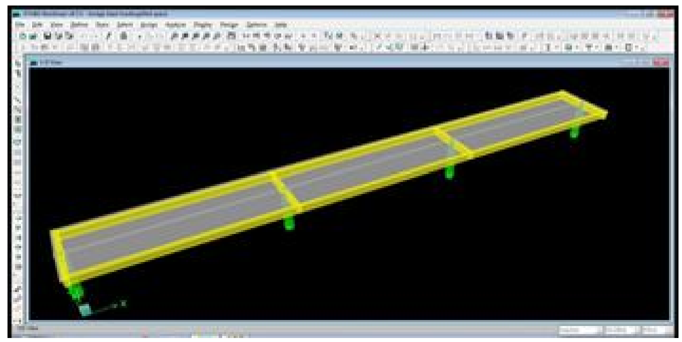

Figure 2. 3D Elevation of Modeled bridge.

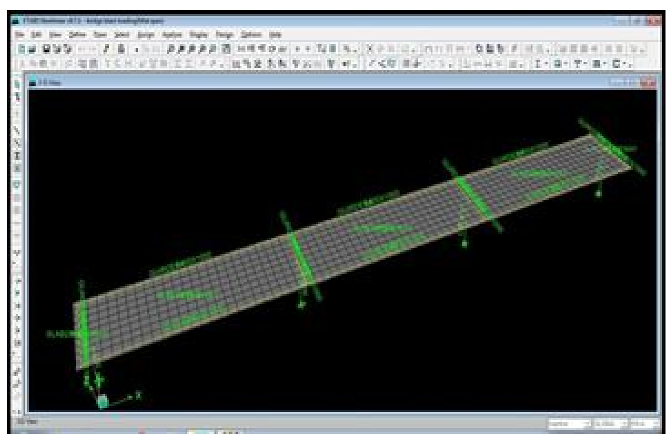

Figure 3. 3D view with section details and object meshing.

3. ETABS Software

ETABS is a powerful program that can greatly enhance an enginees 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.

4. 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.

5. Calculations of the Blast pressure

1. The dynamic pressure at the detonation wave-front is the detonation pressure p1 given in kilo-

bars by the empirical equation, $\mathbf{p_1=2.5 \times 10^{-9} D^2}$
where,
ρ (kg/m3) 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 ps in the near field (for ps> 10 bar) and medium to far field (for ps between 0.1 to 10 bar) where,

$$Ps = \frac{6.7}{Z^3} + 1\ bar (Ps > 10\ bar)$$

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

Z is scaled distance from eqn2.1

From equation 2.1 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.

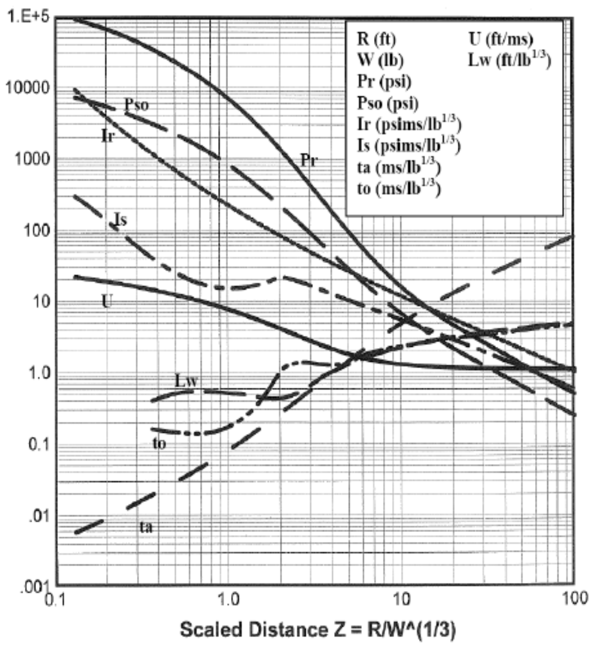

Figure 4. Positive shock wave parameters at various scaled distances(TM5-1300)

1. 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 2.5and table 2.1 represents the pressure computation at the intervals.

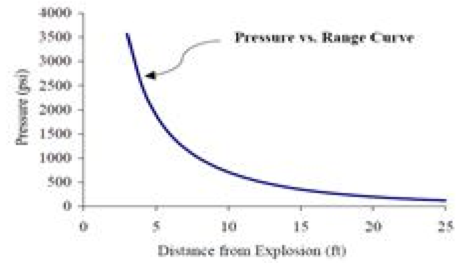

Figure 5. Variation of Pressure with Distance from Explosion[1].

Table 2. 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

III. 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 3.1.

1. 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.

WT = 1.5 DL + 1.5 LL + 1.00 EV........... (3.5)

Where, WT= 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. Various Load Cases.

LoadCase	Location	MemberAffected	TNT equivalent explosive	Blast Set-backs
Case1	Overthe bridge at mid-span.	Deck Slab, Girder.	226.8 kg	1m above the deck.
Case2	Over the bridge at mid-span.	Deck Slab, Girder, .	226.8 kg	1 m above the deck.

IV. 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.

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. Pressure intensities for case 1.

StandoffDistance (m)	PressureIntensities (Mpa)
4	22.52
3.2	18.016
2.4	13.512
1.6	9.008
0.8	4.501
0.0	1.465

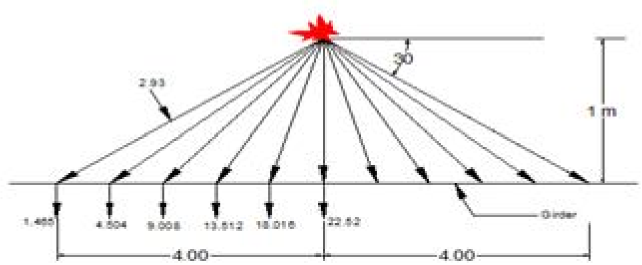

Figure 6. Blast pressure distribution for Case 1.

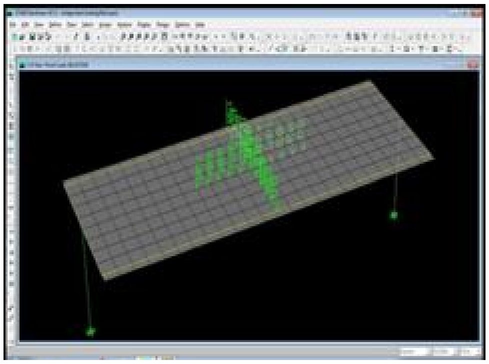

Figure 7. Blast LoadDistribution for Case 1 in ETABS.

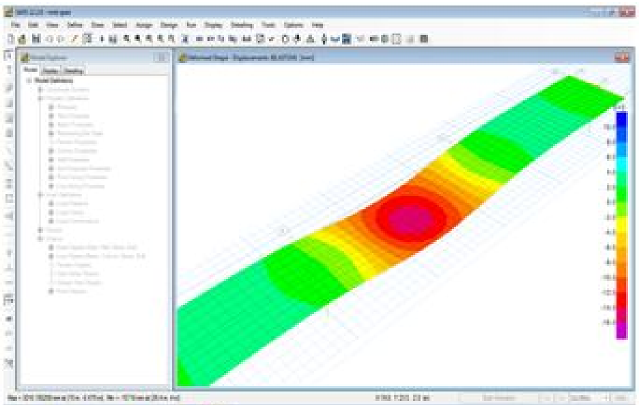

Figure 8. Deformation or Displacement of deck due Blast Load.

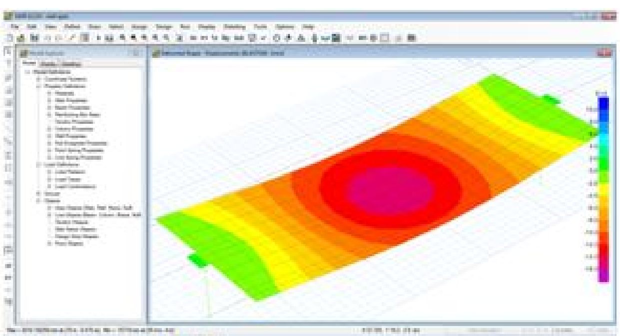

Figure 9. Displacement contour of deck due Blast Load.

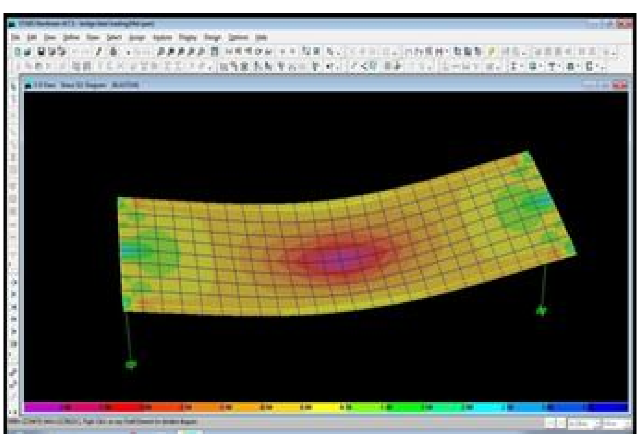

Figure 10. Stress contour of deck due Blast Load.

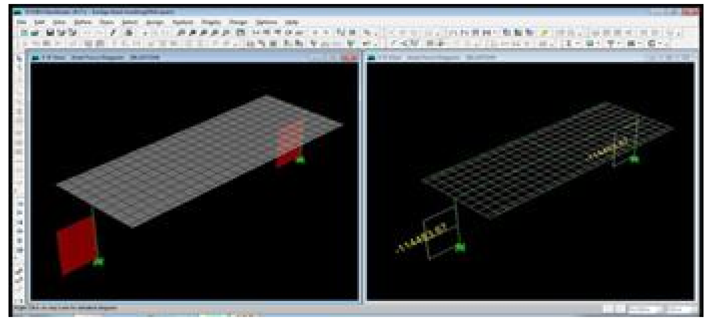

Figure 11. Axial Loads on Column C2 and C3 due to Blast Load.

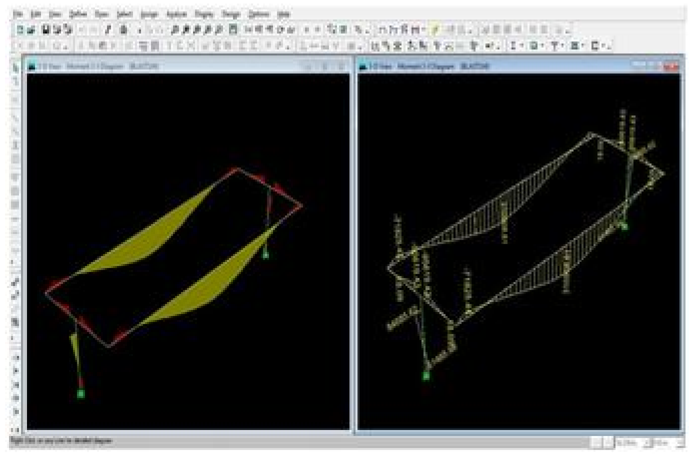

Figure 12. Bending Moment diagram of girder due to Blast Load.

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.

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 5. Pressure Intensities for case 2.

StandoffDistance (m)	PressureIntensities (Mpa)
4	9.10
3.2	7.28
2.4	5.46
1.6	3.64
0.8	1.82
0.0	1.265

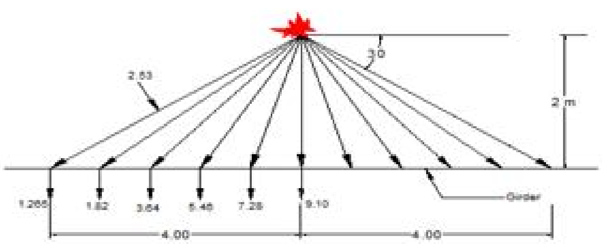

Figure 13. Blast pressure distribution for Case 2.

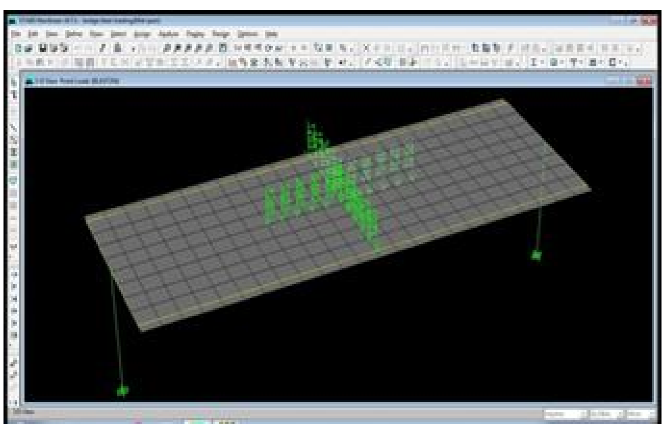

Figure 14. Blast LoadDistribution for Case 2 in ETABS.

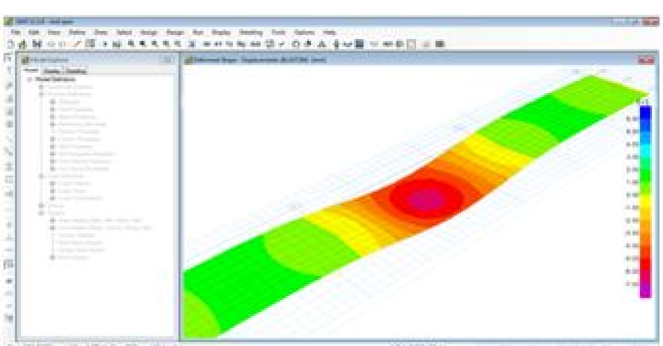

Figure 15. Deformation or Displacement of deck due Blast Load.

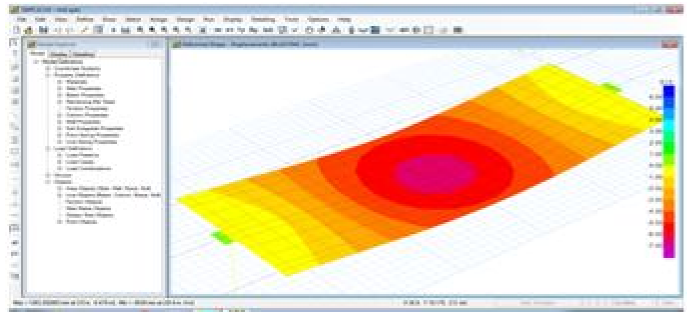

Figure 16. Displacement contour of deck due Blast Load.

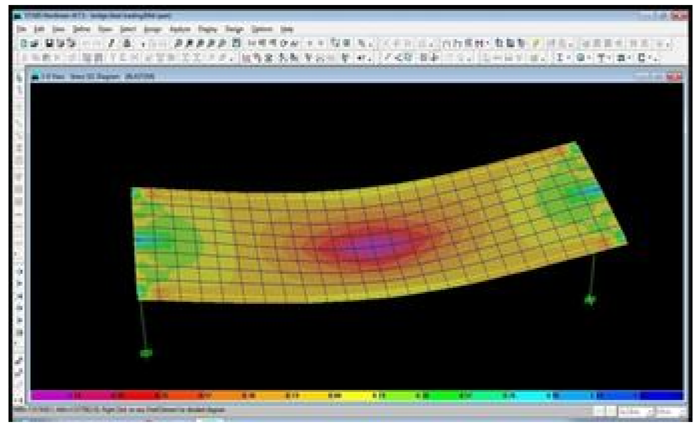

Figure 17. Stress contour of deck due Blast Load.

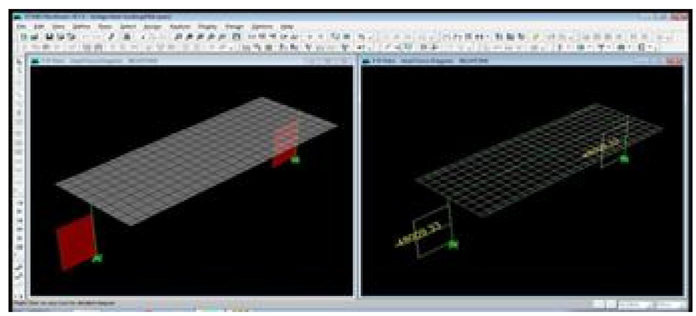

Figure 18. Axial Loads on Column C2 and C3 due to Blast Load.

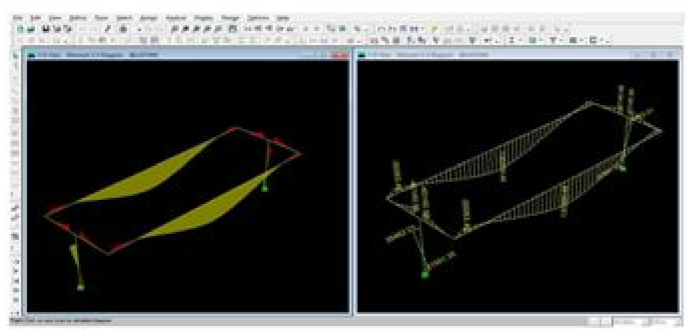

Figure 19. Bending Moment diagram of girder due to Blast Load.

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.

V. 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.
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
5) Blast loads were determined as a record of pressure-time history with the parameters calculated as per available literatures
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.

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