Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 3, Issue 3; January-March, 2016, pp. 223-227

http://www.krishisanskriti.org/Publication.html

Analysis of T-Beam Bridge Subjected to Blast Loading using FEM-SPH Coupling

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Abstract—*Terrorist activities around the world have increased at an alarming rate. This has stimulated the need to design structures considering blast loads. The main objective of this study is to find the percentage of failure at the most critical blast location for each component of the bridge. In this study a 3-Span, 2-Way T-Beam Bridge has been used for the modelling. Loads and design factors have been taken according to Indian Standard Codes. Finite Element Method has been coupled with Smooth Particle Hydrodynamics for the study. The analysis by Smooth Particle Hydrodynamics is considered more accurate as compared to analysis done by Finite Element Method. Finite Element software LS Dyna has been used for all the computational work. The bridge failed under probable blast loads applied above and below the deck. The results show that a typical T-Beam Bridge is not capable of resisting blast loads*

1. INTRODUCTION

Structures are under constant danger because of recent terrorist attacks around the world. Bridges play an important role in the transportation system of a nation. Therefore, they are highly prone to terrorist attacks. Also, the existing bridges are under risk of failure from probable blasts as they have been not designed to resist these loads. Due to the terrorist activities in recent years there has been an awareness to design buildings considering blast loads. Also, some measures are being coined to protect the already existing structures from these high impact loads.

Indian Standard Codes have provisions based on probability analysis for design of various dynamic loads such as seismic loads. However, there is no provision for blast loads. To cater to this need many research projects are going on in various IITs and NITs. These projects focus basically on the nature of blast waves, the loads imposed by a blast on nay structure, examining the response of a structure to these loads.

The purpose of the researches going on in this field is to is to collect adequate data and find out the most economical and effective method of design against blast loading. Major bridges have been continuously under supervision due to risk of terrorist activities. However, thousands of bridges are still unprotected and are under high risk. T-Beam Bridges are the most commonly used concrete bridge type. Their performance has therefore been checked in case of a blast. The research has been done in order to enable the designers to know the necessary structural design requirements. This will also help in finding out the necessary steps for retrofitting of already existing bridges. This will help in reducing the amount of damage and will therefore prove beneficial in saving human lives and monetary losses.

1.1 Blast Loading

T. Ngo has defines an explosion as a large-scale rapid and sudden release of energy [8]. Extremely hot gases at very pressure are produced during a blast. These gases force out the air around the blast centre because of sudden increase in volume of surrounding air due to high temperatures. This pushing out of surrounding air creates a wave known as the blast wave. The blast wave increases the value of pressure to a peak value in a short duration of time and then slowly decreases to atmospheric pressure. The value of pressure then sinks to a value lower than the atmospheric pressure and then slowly reaches back to atmospheric pressure. If the values of pressure are plotted on a graph, the portion above the ambient pressure is called the positive phase and the portion below the ambient pressure is called the negative phase. Fig 1 shows the ideal Pressure-Time graph of blast wave.

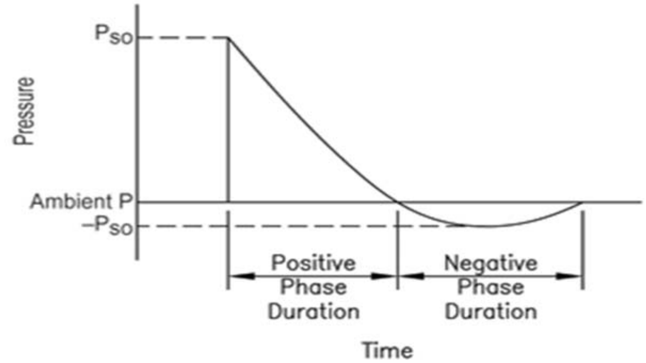

Fig. 1: Pressure-Time Graph of Blast Wave

1.2 FEM-SPH Coupling

Finite element method is a method of analysis in which the entire structure is modelled as mesh elements. It is a fast method of analysis as it takes less computation time. On the other hand, Smooth Particle Hydrodynamics is a mesh less method of analysis. In this method the structure is assumed to behave like a fluid. In comparison to FEM, Smooth Particle Hydrodynamics is a slower process of analysis because of huge computation time. However, SPH method is more accurate method of analysis as compared to FEM. Thus, to obtain more accurate results in lesser computational time FEM-SPH coupling method is used. This coupling can be of two types: In the first type, the modelling is done by FEM and then the entire structure is converted to SPH. In the second type, the modelling is done by FEM and then only a small part is converted to SPH. In this paper, the second type has been used as it takes lesser computation time.

2. NUMERICAL MODELLING

All the components of the bridge were modelled using LS-Dyna. LS-DYNA is a user friendly general-purpose finite element software for numerically solving a wide variety of structural engineering problems. More than 100 different types of elements constitute the element library of LS-DYNA. The hypothetical bridge is a live RCC T-Beam bridge taken from Standard Plans for Highway Bridges issued by Ministry of Surface Transports. The bridge consists of a 12m span and 12m width including a two lane carriageway of 7.5m and a foot path of 2.25m on either side. The bottom of the bridge deck consists of four longitudinal girders at a spacing of 2.65m and cross girders spaced at a distance of 6m center to center, transverse to the longitudinal girders. Three spans of the bridge are considered for modeling.

In LS-DYNA, elements can be meshed either by the Lagrangian mesh or the Eulerian mesh. Mesh nodes moves with material in Lagrangian mesh while material transfers among elements with fixed nodes in Eulerian mesh. Hence, the Lagrangian mesh is used for simulations with relatively small deformation. Constitutive equations can easily be applied to the Lagrangian element, which makes it suitable for simulation of structures. Although large deformations occur when bridge member elements are subjected to blast loads, element eroding technique is used to avoid severe element distortion during the simulation (calculation) of blast load effects. For the numerical simulation of RC structure, three dimensional solid element was used for modeling of non-linear behavior of concrete, three dimensional beam element was used for modeling of reinforcement.

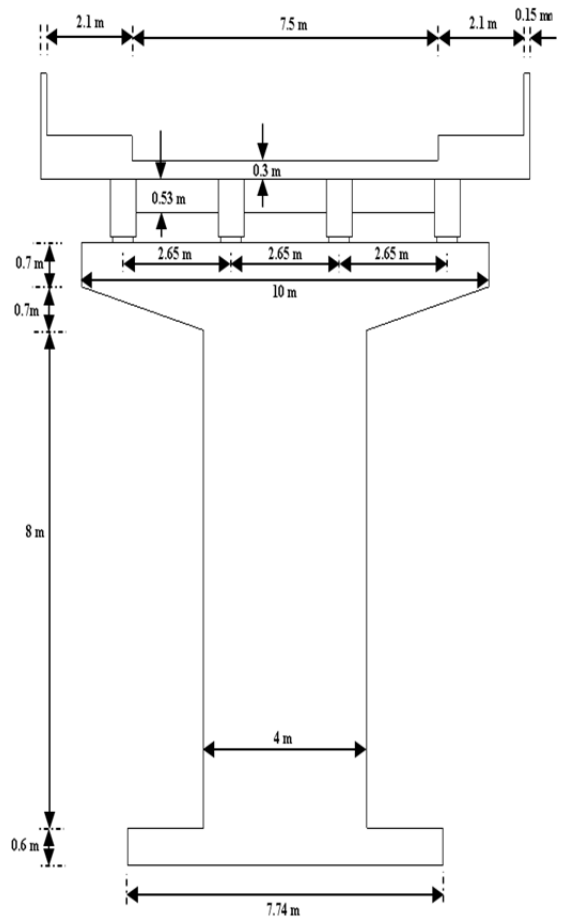

Fig. 2: Sectional View of T-Beam Bridge

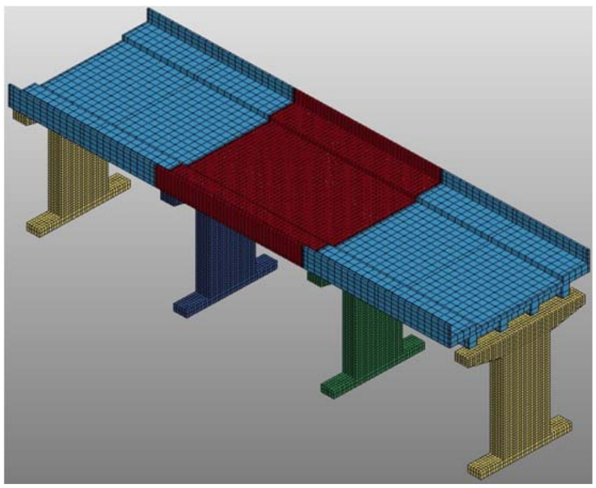

Fig. 3: Isometric View of T-Beam Bridge

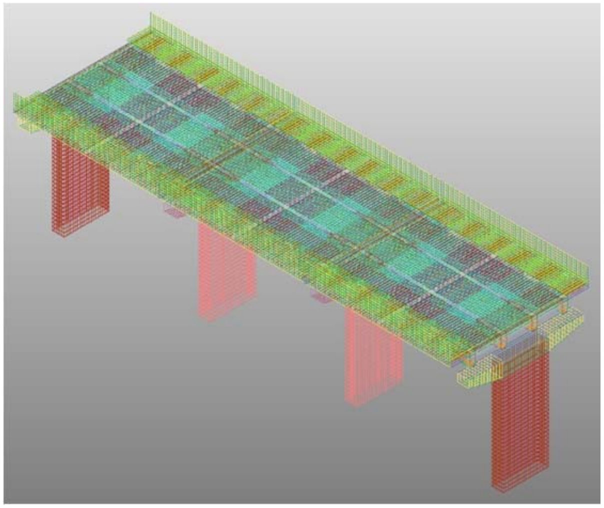

Fig. 4: Reinforcement Details of T-Beam Bridge

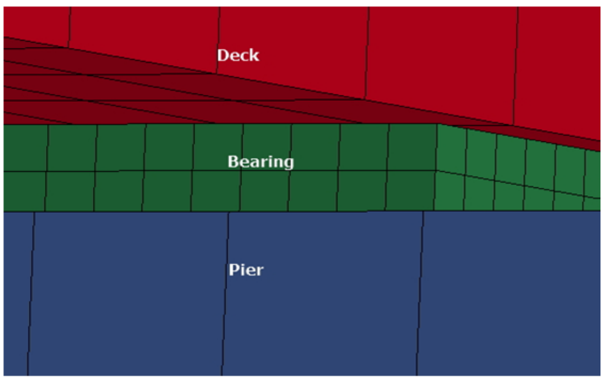

Fig. 5: Deck, Bearing and Pier Connection

3. MATERIAL MODELLING

3.1 Air

The ideal equation of state has been used for air. In an ideal gas, the internal energy is a function of temperature alone and if the gas is polytrophic the internal energy is directly proportional to temperature. The values of the constants used for air are presented in Table 1.

Table 1: Properties for Air

Equation of State	Ideal gas
Reference Density	1.225E-3 g/cm3
Reference Temperature	288.2 K
Specific Heat	717.3 J/kgK

3.2 TNT

The quantity of explosives taken in this experiment is 226.8 kg of TNT. Lee-Tarver equation of state (Lee and Tarver, 1980) is used to model both the dimension and expansion of TNT in conjunction of with "Jones-Wilkins-Lee" (JWL EOS) to model the explosives. The values of the constants used for TNT are presented in Table 2.

Table 2: Properties for TNT

Equation of state	JWL
Reference Density	1.590 g/cm3
C1	3.7377E8 kPa
C2	3.7347E6 kPa
C-J, Detonation Velocity	6930 m/s
C-J, energy/unit volume	6E6 KJ/m3
C-J, Pressure	2.1E7 kPa
R1 and R2	4.15 and .9

3.3 Concrete

Grade of concrete used for the bridge design is M30. To assign this property of the concrete the constitutive material model MAT_CSCM_CONCRETE was used. CSCM models employ three strength surfaces; Yield surface, Limit surface, and Residual surface along with cap hardening parameters. The parameters of the constitutive model has been presented in Table 3.

Table 3: Properties for Concrete

Model	CSCM
Mass density	Kg/m3
Erode	1.05
Compressive strength	3E7 Pa
Maximum aggregate size	20 mm

3.4 Steel

Reinforcement provided in the deck, the piers and the girders have been modeled as beam elements and are constrained within the concrete domain. Fe 415 steel has been used in all places and the properties have been assigned via MAT_PIECEWISE_LINEAR_PLASTICITY constitutive model. The values of the constants used for steel are given in Table 4.

Table 4: Properties for Steel

Mass density	7850 kg/m3
Young's modulus	2E11 Pa
Poisson's ratio	0.3
Yield stress	4.15E8 Pa
Tangent modulus	1.8E10 Pa
Failure	0.145

4. BOUNDARY CONDITIONS

In order to fulfill different end conditions, various boundary conditions have been applied. The bottom portion of pier has been kept fixed in all the directions. The reflected boundary condition has been used throughout the air domain. Flow out of air and TNT has also been allowed in all external limits of air mesh.

5. CONTACT

The bonding between re-bars and concrete has been assigned through a constraint model known as CONSTRAINED_LAGRANGE_IN_SOLID. The contact between various components of bridge i.e. Deck-Bearing, Bearing-Pier has been provided by using CONTACT_SURFACE_TO_SURFACE.

6. LOCATION OF BLAST LOAD APPLICATION

The deck slab has mostly been affected due to possible explosion on the top of bridge deck. Not only the deck but also the piers have been severely affected. The loads are distributed on the deck slab and ultimately applied as uniformly distributed load. The blast location has been chosen based on the members affected as shown in Table 5.

Table 5: Critical load cases

Load Cases	Location	Members Affected	Type of Blast
1	Above Bridge Pier	Deck Slab, Girder	Surface
2	Above Deck End Girder	Deck Slab, Girder	Surface
3	Above Deck-Center	Deck Slab, Girder, Pier	Surface
4	Below Deck-Center	Deck Slab, Girder, Pier	Surface

7. RESULTS & DISCUSSION

The results obtained by applying blast load at different locations showed that T-Beam bridges are severely damaged by blast loads. When the blast is applied above the center of deck, the bridge shows almost complete destruction. It can be concluded from this result that application of blast at center position is the most critical condition. The various results obtained after simulation are shown in Fig. 6-8 given below.

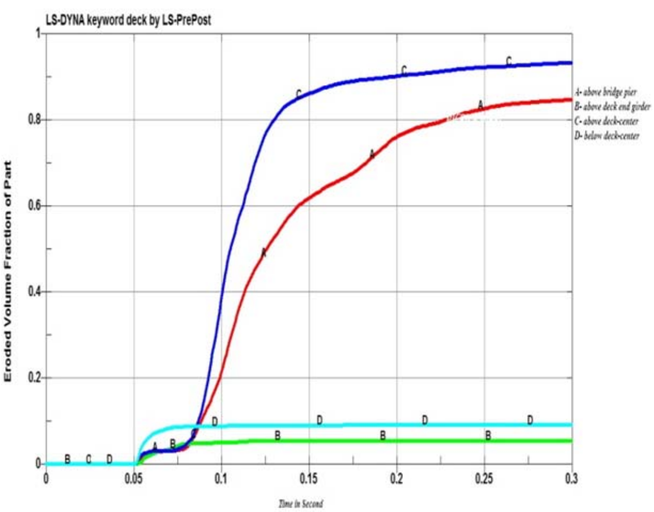

Fig. 6: Comparision of Eroded Volume of Deck for Different Loading Conditions

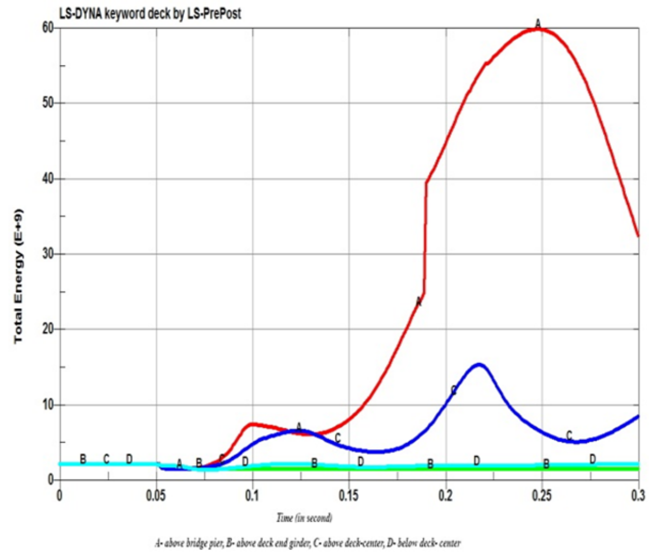

Fig. 7: Total energy v/s time

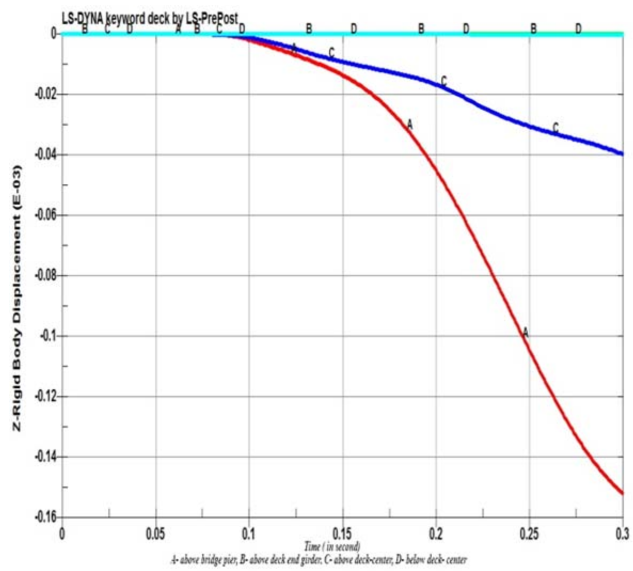

Fig. 8: Rigid displacement v/s time

For damage mechanism, strength of concrete used in column and reinforcement detailing at the bottom of pier are the most important parameters since the concrete at the bottom of pier gets eroded.

Blast wave cause large amount of erosion of concrete. Reinforcement bars don’t show any damage. There is more erosion of concrete at the opposite surface of the element as compared to the surface on which the blast has been applied.

8. CONCLUSION

Based on this study, the following conclusions can be made:

1. To protect bridge from blast loading, there is need to consider blast loading at the time of design of structure. For already existing structures, retrofitting techniques can be adopted or a blast barrier can be made throughout the structure.
2. It was found from the result that a typical T-Beam Bridge will fail due to blast load applied by an explosion of 226.8 kg of TNT above and below the bridge deck.
3. Some part of the bridge is expected not to fail after application of blast load if location of blast is near the column.
4. If blast occurs near girder, some of the girder on other spans are expected not to fail.
5. When blast load is applied near the column, bridge is going to settle immediately.
6. It can be determined from this study that a typical T-Beam bridge with concrete columns and piers is not capable of resisting specific blast load.

9. ACKNOWLEDGEMENTS

This work was carried out in National Institute of Technology Durgapur.

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