EFFECTS OF BLAST LOADING ON R.C.C. BRIDGE PIERS

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ABSTRACT— The design of structures to resist blast loads has traditionally been considered only for essential government buildings, military structures, and petrochemical facilities. Until recently, however, little attention has been given to bridges. One strategically placed truck bomb on a critical bridge could result in significant loss of life, severe structural damage, and devastate an economy. Recent terrorist threats to bridges have demonstrated the vulnerability of our transportation infrastructure and reinforced the need for bridge security.

This paper summarizes the results of ongoing research to develop performance-based blast design standards specifically for bridges. The goal of the research is to investigate economical, and effective methods to mitigate the risk of terrorist attacks against critical bridges. The potential effects of blast loads on bridge substructures are presented, and structural design and retrofit solutions to counter these effects are discussed.

KEYWORDS – Bridge, Blast Load, Retrofit, Mitigate.

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1. INTRODUCTION

The number and intensity of domestic and international terrorist activities, including the September 11, 2001 attack on World Trade Center towers in New York, have heightened our concerns towards the safety of our infrastructure systems. Terrorists attack targets where human casualties and economic consequences are likely to be substantial. Transportation infrastructures have been considered attractive targets because of their accessibility and potential impacts on human lives and economic activity. Duwadi from Federal Highway Administration (FHWA) realizes that bridge is vulnerable to physical, biological, chemical and radiological attack in addition to natural hazards and FHWA prepares for the next generation of bridges and tunnels that are redundant and resilient to withstand unforeseen events [Duwadi and Chase (2006); Duwadi and Lwin (2006)]. An Al Qaeda terrorist training manual captured in England contains goals that included missions for “gathering information about the enemy and blasting and destroying bridges leading into and out of cities.”[TxDOT (2002)].

Bridges are very complex and varied systems. Decisions relating to blast threats (magnitude and location), affected bridge components by direct blasts, as well as existing redundancies of bridges can be daunting, even for the simplest of bridges. The Blue Ribbon Panel placed first priority on deterrence, denial and detection of blasts, second on defense with standoff and third on structural modifications through design and detailing. Highway bridges are readily accessible to vehicles that can carry explosives. Continuous monitoring of even critical bridges and inspection of vehicles approaching these bridges will require tremendous funds and other resources. Barrier standoffs may be effective in reducing the destructive effects of blast loads on bridge piers. The BRP has recommended minimum barrier standoffs for different vehicular threat types in terms of explosive weight (lbs TNT). However, for different reasons, it may not be possible to provide adequate standoff to protect bridge piers on busy highways. In such cases, strengthening of bridge components becomes the only viable protective option.

2. LITERATURE

There are few works carried out by researcher, Eric B. Williamson, Oguzhan Bayrak, Carrie Davis and G. Daniel Williams (2012) worked on a experimental research program on ten different half-scale column designs in which the design parameters that have the greatest impact on the performance of blast-loaded bridge columns were evaluated. Experimental observations were used to evaluate the performance of several design parameters and to determine the capacity and failure limit states of reinforced concrete highway bridge columns subjected to large blast loads. [1]. Eric B. Williamson, Oguzhan Bayrak, Carrie Davis and G. Daniel Williams (2012) worked on experimental research programs to assess the performance of blast-loaded reinforced concrete columns. The test program included 10 small standoff blast tests against eight different column designs. Results from the test program demonstrate that the performance of reinforced concrete columns subjected to blast loads is highly dependent upon the scaled standoff. [2].Shuichi Fujikura and Michel Bruneau worked on the Blast testing they conducted a 1/4 scale ductile RC columns, and nonductile RC columns retrofitted with steel jacketing. The new approach of Multihazard engineering is proposed as the search for a single design concept which can satisfactorily fulfill the demands of multiple hazards. [3]. Z. Yi, A. K. Agrawal, M. Ettouney, and S. Alampalli worked on a new approach, named the hybrid blast load (HBL) method, is proposed. They focused 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 LS-DYNA offer detonation simulation capabilities to propagate blast loads through air medium. [4]. Z. Yi, A. K. Agrawal, M. Ettouney, and S. Alampalli worked on the use of a circular column has been found to be an effective way of decreasing the blast pressure to a square or rectangular column of the same size. A minimum column diameter of 762 mm (30 in.) has been recommended for columns subjected to close-in blast loads.

For small standoff threats, continuous spiral reinforcements have been observed to perform better than discrete hoops with standard hooks [5].

From the literature review it is observed that the research was done to find out the effect of damage on bridge column mostly by experimental studies. Therefore the present work aims to study the effect of blast analytically at various stand-off distances and its mitigation techniques.

3. AIM

To analyze the Effect of Blast Loading on Bridge Piers

4. METHODOLOGY

First, the detail study will be made from the various literatures for bridge column design. The various parameters of blast such as stand-off distances, scaled distances, peak pressure, side on pressure, ambient air pressure etc were studied. The Study of blast loading on bridge pier and designing details as per IS 4991-2003. The pier design as per IS 4991-2003 for blast loading was checked with analytically using ANSYS software. The pier modeling is done in ANSYS for charge of 200 kg, 500kg, 800kg and 100kg at various stand-off distances- 15feet, 30feet, 50feet, and 100feet etc and analysis is done. The minimum stand-off distance for which the pier can resist the forces was determined. Comparative study was carried out for different stand-off distances. Therefore in this paper work is focused on substructure explosions.

A. BLAST LOAD PROPAGATION

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 fig. 1. The shock wave is accompanied by blast wind causing dynamic pressure 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

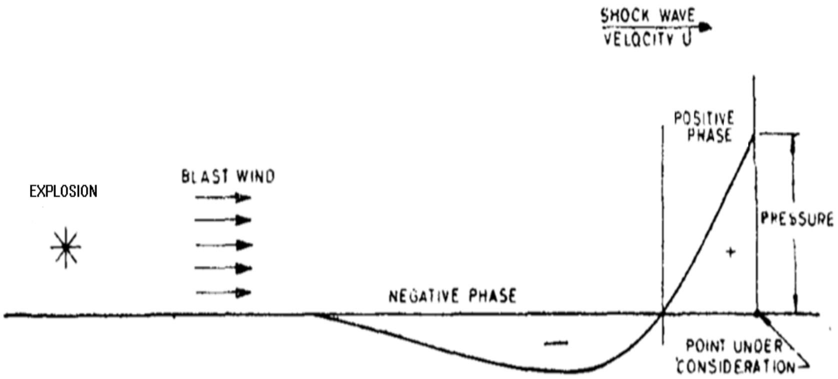


FIG SOURCE (IS 4991 -2003)

Fig 1. Shock Wave Produced By Blast

B. DESIGN RECOMMENDATIONS

The following design and detailing recommendations have been developed from the experimental observations and the test data collected during this research project. The recommendations provided in the following are presented in a manner that is intended to be consistent with the AASHTO-LRFD specifications (2003) and are formatted somewhat differently than the previous sections.

C. DESIGN CATEGORY

After the completion of a preliminary risk assessment, the design category for a blast-loaded, reinforced concrete bridge column can be established. A preliminary risk assessment involves carrying out a threat point-of-view analysis to identify and prioritize the various potential threat scenarios that can occur. Such information can be used to determine whether or not specific consideration for blast loads is needed and, when necessary, to develop mitigation strategies for those threats that may be of concern. In assessing risk for a given bridge, factors such as the bridge's importance, nearest detour route, average daily traffic, whether or not the bridge is on a critical emergency evacuation route, and time needed for repair/ replacement need to be considered. Because of space limitations, the topics of risk assessment and risk management for bridges subjected to potential terrorist incidents are not covered in detail; however, additional details can be found in several sources including Williamson and Winget (2005) and Ray (2007). Design Categories A, B, and C for blast-resistant design of bridge columns are described in the following. These categories may require additional refinement or augmentation based on future research that considers load scenarios other than those considered during this research (e.g., multiple detonations or vehicle impact coupled with blast). Each design category described in the following specifies design and detailing guidelines recommended for a blast-loaded column depending on the scaled standoff, Z:

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

Where R = standoff distance between the blast source and target (ft); and W = charge weight [equivalent weight of TNT (lb)] (Dept. of Defense 2008; Tedesco et al. 1999).

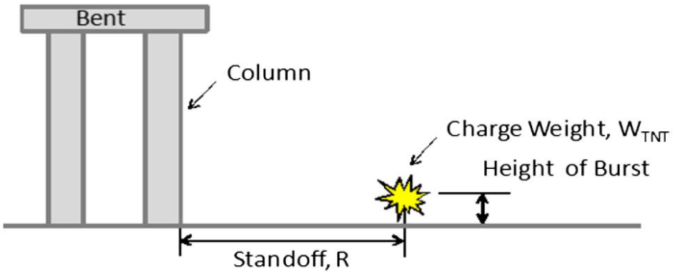


Figure no.2- Stand-off distance

The scaled standoff, Z, is widely used in blast-resistant design as a means of indicating blast load intensity (Dept. of Defense 2008). In an effort to provide guidelines for the blast-resistant design of reinforced concrete bridge columns in a manner that is consistent with practice, this parameter is used to define the design categories as described below.

1. Design Category A:
   $Z > 3$
2. Design Category B:
   $3 \geq Z > 1:5$
3. Design Category C:
   $Z \leq 1:5$

1. DESIGN CATEGORY A

Highway bridge columns in Design Category A do not require any specific design modifications for blast resistance and should follow the design and detailing provisions required by the AASHTO LRFD Bridge Design Specifications (2007) for the normally anticipated loading conditions in the region where the bridge will be located. Thus, Category A columns should be designed ignoring blast loads. Bridge owners have supported the designation of such a design category because it allows for the possibility that not all bridge columns will be required to be designed to resist blast effects. For cases in which threat levels are low, there is no need to include a design case specifically for blast. As the threat level increases, however, consideration will need to be given to potential blast loads when establishing column detailing requirements. Design Categories B and C describe these requirements.

2. DESIGN CATEGORY B

Highway bridge columns in Design Category B should follow the seismic design and detailing provisions required by the AASHTO LRFD Bridge Design Specifications (2007). The Caltrans Seismic Design Criteria (2006) and Caltrans Bridge Design Specifications (2003) are additional resources for design and detailing requirements. The only exceptions to these specifications for blast resistant design are as follows: (1) a more stringent extension length on hooks for discrete ties or hoops should be used; and (2) the application of transverse reinforcement detailing for the plastic hinge region should extend over the entire column height. Hooks should consist of a 135°-bend, plus an extension of not less than the larger of 15:0db or 7.5 in. (191 mm) (Bae and Bayrak 2008). The requirement of additional transverse reinforcement over the entire column height is intended to account for the uncertainty associated with potential blast scenarios. The proposed increase in hook length over current provisions is based on the results of an extensive testing program that included full-scale specimens evaluated under severe seismic loading (Bae and Bayrak 2008). For these tests, long hooks performed satisfactorily, whereas the standard seismic hooks consisting of a 135°-bend plus an extension of 8:0db opened under the extreme loads. Blast and seismic loads are both dynamic loads that induce dynamic structural responses and inelastic behavior. To allow the formation of plastic hinges and to achieve a favorable response, adequate anchorage into the core concrete must be provided over the entire column height.

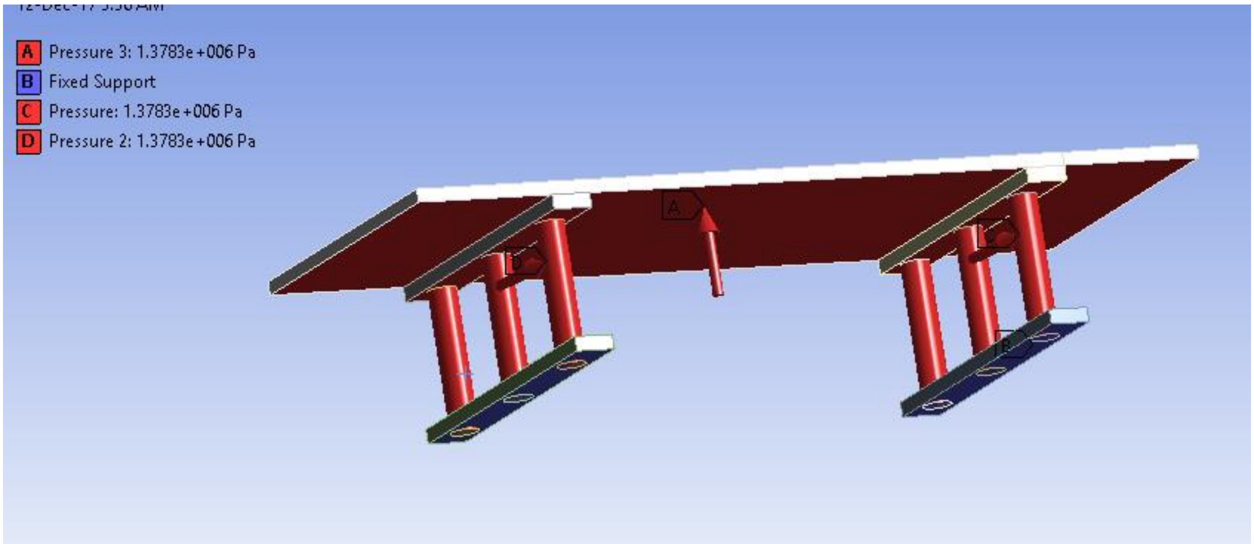
3. DESIGN CATEGORY C

Blast loads acting on highway bridge columns that fall into Design Category C place large demands on column performance. Of course, rather than designing for such severe threats through structural detailing, it is possible to reduce the demand by establishing sufficient standoff to place the column under consideration into Design Category A or B. Standoff can be established with physical deterrents such as bollards, security fences, and vehicle barriers. If standoff cannot be increased, design for Category C performance will be necessary. Highway bridge columns in Design Category C should follow, as a minimum, the design and detailing provisions of Design Category B. The following requirements place additional design and detailing requirements on blast-loaded columns to further improve column survivability.

4. MODELING

According to Krauthammer and Otani (1997), a detailed modeling of rebars is important for the simulation of blast load effects on concrete structures. Generally, reinforced concrete members are modeled by an equivalent monolithic element that can represent combined behavior of both concrete and steel during hazards such as earthquakes, wind, etc. We prepared model of bridge pier in SAP2000 as shown in figure for various stand-off distances such as 3m, 3.5m, 4m, 4.5m and 5m.

The bridge chosen for analysis consists of two 26-meter (85-foot) main spans, with a 4.8-meter (16-foot) clearance and total deck width of 14 meters (46 feet). It contains three concrete piers per bent spaced at 5.2 meters (17 feet), each with a 0.9 meter (3-foot) diameter. Terrorist threat scenarios were chosen for analysis of the substructure, based on a preliminary vulnerability assessment. These general courses of action consisted of a vehicle bomb below the deck



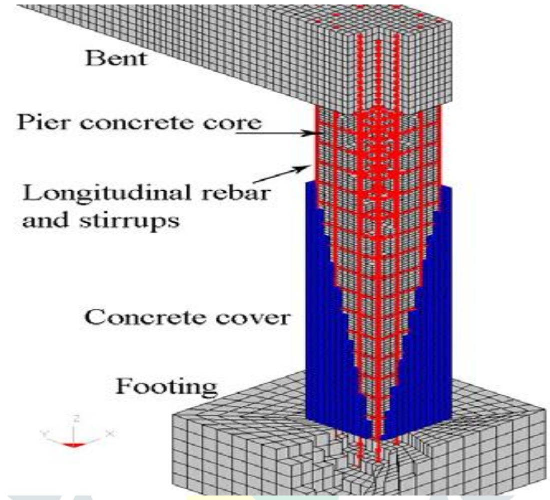


Figure no.3- Bridge Pier model

5. SUMMERY AND DISCUSSION

•In the present work we studied to shed light on blast resistant bridge pier theories, the enhancement of bridge security against the effects of explosives in both architectural and structural point of view and the analysis techniques that should be carried out. In the present work we studied about Blast mechanism, the various types of blast such as commonly used blast TNT and Blast Mitigation Techniques. We came with the following conclusion.

•We studied blast mechanism; Different terms related to blast, characteristics of blast etc.

•Study of different Blast Mitigation Techniques and their applications was studied.

•We studied analysis of blast resisting bridge pier.

•From non-linear dynamic analysis of bridge pier subjected to blast load with 200kg, 500kg. 800kg and 1000kg charge weight, following conclusions are drawn.

•For 200 kg TNT there is 40.82%, 36.10% & 27.83% increase in deformation, Normal strain, equivalent strain, Strain energy, and normal stress respectively.

•For 500 kg TNT, due to infill there is 44.96%, 32.87% & 23.03% reduction in displacement, velocity and acceleration respectively.

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