Blast Load Analysis on Bridge Pier Subject To Various Standoff Distance

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Abstract- *Need for designing certain important structures to resist blast loads is increasing in the recent past years, due to the enhanced terrorist operations. A bomb explosion can cause very serious damage on the bridge pier's external and internal structural frames. Collapse of one structural member in the vicinity of the source of explosion, may then create critical stress redistributions and lead to collapse of other members, and eventually of the whole structure. Due to the threat from such extreme loading conditions, efforts have been made to develop methods of structural analysis and design to resist blast loads. The analysis and design of structures subjected to blast loads require a detailed understanding of blast phenomena and its effects on various structural elements. Blast loads are in fact dynamic loads that need to be carefully calculated just like earthquake and wind loads. The study of effect of blast loading on a Bridge pier is carried out. Effects of variable blast source weight (100kg, 200kg, 300kg, 400kg & 500 kg of TNT) are calculated by considering 30 m distance from point of explosion for bridge pier with and without soft storey. The calculations of blast load on bridge pier for all cases are carried out by using IS 4991 (1968) (Criteria for Blast Resistant Design of Structures for Explosions Above Ground).The blast load is analytically determined as a pressure-time history and structural response predictions are performed with a commercially available three-dimensional finite element analysis programme using non-linear direct integration time history analyses.*

I. 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.

A Blue Ribbon Panel (BRP) consisting of bridge and tunnel experts from professional practice, academia, federal and state agencies and toll authorities was convened in 2003 to examine bridge and tunnel security and to develop strategies and practices for deterring, disrupting, and mitigating potential attacks. The BRP, sponsored jointly by the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials, acknowledged that the nation’s bridges and tunnels are vulnerable to terrorist attacks. The statistics of worldwide attacks against bridges were recorded by the Mineta Transportation Institute indicated that 53 terrorist attacks between 1980 and 2006, and 60% of those attacks were explosions.

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. Highwaybridges 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.

Loads imposed on 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.

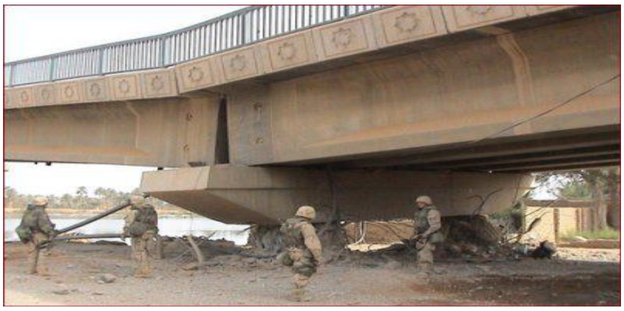


Fig 1 A bridge in Iraq damaged by a relatively small amount of explosives placed in a Terrorist attack.

Nature of Explosions

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 [Mays and Smith (1995)]. High explosives produce a shock wave along with gas, and the characteristic duration of a high-explosive detonation is measured in microseconds (s). Explosives come in various forms, commonly called by names such as TNT, PETN, RDX, and other trade names [USDOA (1998)].The lethality of high explosives has been increasing since the nineteenth century [Baker et al. (1983); Fickett (1985); McGraw-Hill (1989)].

Blast Loads

Blast loads are considered one of the extreme loads affecting structures, and even a small amount of explosive can produce severe localized damage to the structure. In some cases this localized severe damage can potentially progress to global collapse of the entire structure. An explosion starts when a high explosive material is detonated forming a detonation wave in the material. The detonation wave typically moves at velocities of 18,000 ft/s to 20,000 ft/s and is pressurized at up to 4×106 psi with temperatures in the range of 8,000°F. This hot gas is expanded, as a rapid release of energy occurs. A shock front moving at supersonic velocity is formed in front of this gas and is called the blast wave or shock front. This wave propagates outward in all directions from the detonation center. The front of the wave, or the shock front, travels faster that the speed of sound. The flow of the air mass behind the shock results in an outward movement of air and debris causing drag loading on the structure and is known as the dynamic pressure. This dynamic pressure loading is a function of the structural shape, incident pressure, air density, and the explosive material. Figure 1.2 shows a typical curve for incident pressure and the dynamic pressure over time.

As seen from Figure 2, the blast load is characterized by a positive phase which is considered in the design and a negative phase which is normally neglected as its effect is very small compared to the positive phase. The reflected pressure shown in Figure 1 is the reflected pressure loading on any structural surface the moving shock front impinges upon.

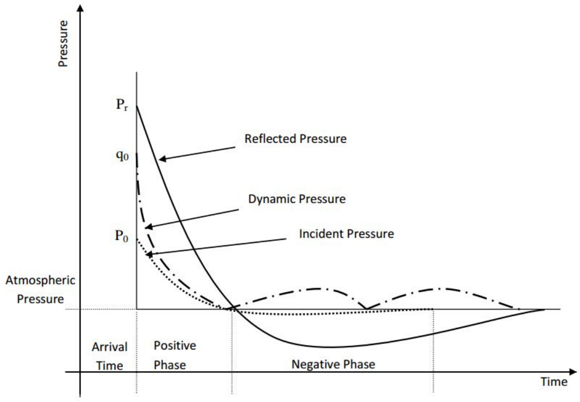


Fig 2 Variation of overpressure and dynamic pressure over time (ASCE, 1997)

Blast on Bridges

The study of the structural and material response of bridges under blast loads are conducted either by experiments or numerical simulations. However experiments are difficult to be done in full scale and are costly to perform. In addition to that, the other important factor is the difficulty of measuring the various parameters in the field for close-in detonations where the instrument is often destroyed and the failure process is difficult to document. Therefore, numerical solutions are considered an attractive approach to evaluating bridge response to explosions and are very important to support any blast experiments on bridges. In a study conducted by Marchand et al. (2004), the structural response of bridge piers subjected to vehicular and hand placed bombs was evaluated. Various standoff distances and charge weights of vehicular bombs were analyzed while the hand placed bomb was used to investigate the impact of a single bomb versus two bombs.

Counterforce bombs are a set of bombs placed on opposite sides of an object so that both sides of the object experience identical pressures (Marchand et al., 2004).

Once the loads were applied and the analysis was performed, it was determined that breaching of the concrete was the main factor that influenced the pier performance in both the vehicular blast and hand placed explosive scenarios. When 3000 and 5000 psi concrete piers were evaluated against one another, there was a 30% increase in breaching when the lower concrete strength was used. An evaluation of the piers when breaching was neglected indicated that the strength played only a small role in the performance of the columns. When breaching was neglected, there was only a 10% difference between the support rotations in the two piers (Marchand et al., 2004).

Objectives of study

1. To study effect & damage pattern of blast on bridge pier.
2. Study of Blast mechanism as per IS 4991
3. Bridge pier analysis with various cross sections such as circular, rectangular using ANSYS workbench.
4. To study stress distribution after blast load is applied and to study load deflection curve

II. INTRODUCTION TO EXPLOSIVE

Blast is an energy distribution process in which a large amount of energy disperses in very, very short time. The time duration for blast/shock environments of interest are typically in the range of .5 to 1.0 ms with loadings in the range of several thousands of pounds per square inch. Although there are different forms of explosive threats [see Smith and Hetherington 1994], 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, in this research, we assume 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 1.3shows a bridge in Palestine after missile attack.

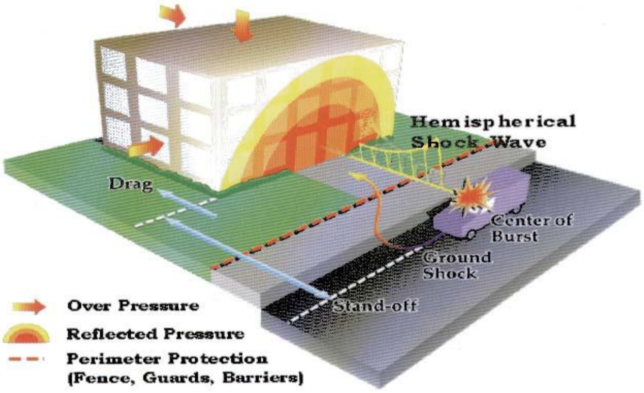


Fig 3: Illustration of Terminologies Used in Defining Blast Loads on Structures.

III. LITERATURE REVIEW

Shuichi Fujikura and Michel Bruneau (2011) The findings of research examining the blast resistance of bridge piers that are designed in accordance with current knowledge and specifications to ensure ductile seismic performance. Blast testing was conducted on 1/4 scale ductile RC columns, and no ductile RC columns retrofitted with steel jacketing. The seismically designed RC and steel jacketed RC columns did not exhibit ductile behavior under blast loading and failed in shear at their base rather than flexural yielding. The objective of the research presented here was to investigate the blast resistance of commonly used bridge columns, namely seismically ductile RC columns and non-ductile RC columns retrofitted with steel jackets to make them ductile, detailed in accordance to recent codes of practice. This paper reports the experimental and analytical investigation of these two types of columns under blast loading.

Eric B. Williamson, OguzhanBayrak, Carrie Davis and G. Daniel Williams (2011) Statistical data from past terrorist attacks show that transportation infrastructure has been widely targeted, and a significant percentage of the attacks against transportation structures have been directed towards bridges. Recent threats to bridges in the United States validate this concern and have attracted the attention of the bridge engineering community. To address these concerns, the National Cooperative Highway Research Program (NCHRP) funded a project at the University of Texas at Austin to study the response of reinforced concrete bridge columns subjected to large blast loads. This test program was unique owing to the size of the specimens tested and the intensity of the loading. Most of the research on protective design reported in the open literature is based on computational studies or deals experimentally This paper includes a description of an 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. Interpretation of the test results and guidelines for the blast-resistant design of reinforced concrete bridge columns Performing large-scale blast tests presents several challenges that are not encountered when conducting small-scale tests. For testing under these conditions, large blast loads need to be generated, which are costly and require working with personnel that are appropriately qualified to carry out this work. 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.

Eric B. Williamson, OguzhanBayrak, Carrie Davisand G. Daniel Williams (2011) Guidelines for the design of critical bridge components subjected to blast loads are currently not available to the general bridge engineering community. Historically, however, transportation assets have proven to be attractive targets for terrorists because of their open access, utilization by large numbers of people, symbolic importance, and significance to commerce, in addition to a host of other reasons. To improve the current state of practice, the National Cooperative Highway Research Program sponsored a research project to investigate the response of reinforced concrete bridge columns subjected to blast loads. An experimental research program 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.

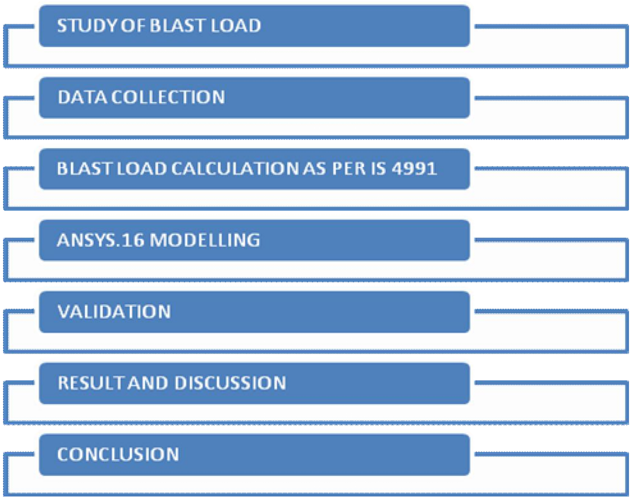
Kiger, Sam A., Hani A. Salim, and Ahmed Ibrahim 2011 In this research, a literature review of the effect of blast loads on bridges is presented. The review indicates a need to establish design criteria for post-tensioned box girder bridges subjected to blast loads, based on numerical and analytical results. This design criterion would predict the relation between the charge size and the damage type (no damage, spall, and breach). For these needs, numerical models based on the nonlinear explicit finite element method were developed to predict the damage type. Specific conclusions and recommendations are presented. This report focuses on the structural and material response of post-tensioned box girder bridges under blast loads. The bridge is simulated using the explicit dynamic finite element hydrodynamic code LSDYNA. It is assumed that the explosive material was located on top the bridge deck. However, when an explosion occurs over the concrete deck of any bridge, the rest of the bridge superstructure could be affected due to the localized damage to the deck. The results and the analyses of various parameters of the box girder bridge on the dynamic response and failure mechanism of the bridge under blast loads are discussed in this report. The main parameters of this study were the high explosive charge size, explosive location over the bridge deck, the material properties of steel and concrete used in the bridge construction, and the effect of prestressing force used in the concrete deck section as a solution to decrease the damage level. One-quarter of the simple span bridge and half scale for the continuous system were modelled taking into account the appropriate boundary symmetry conditions

Z. Yi, A. K. Agrawal, M. Ettouney, and S. Alampalli (2014) Bridges with different seismic design levels and concrete compressive strengths have been analysed for three levels of under deck blast loads. It is observed that there are several other damage modes besides failure of bridge columns that may contribute to a complete collapse of the bridge. In general, it is demonstrated that an increased seismic resistance leads to improved performance during blast loads. Both concrete strength and seismic capacity are equally effective for bridges designed with higher seismic resistance.

The use of a circular column has been found to be an effective way of decreasing the blast pressure and impulse relative to a square or rectangular column of the same size, and the decrease in impulse can be up to 34% for small-scaled standoffs.

1. A minimum column diameter of 762 mm (30 in.) has been recommended for columns subjected to close-in blast loads.
2. For small standoff threats, continuous spiral reinforcements have been observed to perform better than discrete hoops with standard hooks. To avoid anchorage pull-outs and improve the performance of blast-loaded columns A minimum amount of confinement reinforcement should be increased by 50% over the entire column height

IV. METHODOLOGY



Design Consideration

As the impulse of the negative zone is less than the impulse of the positive zone, the negative face is usually not taken into account for the design purpose.

Determining Factors for Blast Parameter

1. Explosive charge weight
2. Stand-off distance

a) Explosive Charge Weight (*W*)

W is expressed in weight or mass of TNT. The equivalent W of any other explosive material is based on experimentally determined factors or the ratio of its heat of detonation to that of TNT.

b) Stand-off Distance *(R) :*

R measures how close to the building a bomb could explode and is therefore a function of the physical characteristics of the surrounding site.

- Scaled Distance

This is the distance from the source of explosion at which the blast effect caused by standard charge weight is just equivalent to as caused by 'W ' charge at distance 'R'.

Scaled distance $Z = \frac{R}{W^{1/3}}$

IS Code Provision:

As per IS 4991 – 1968, the value of the P_{so}, q_s, $P_r$computed from Table 5.1 for 1 tonne detonation amount.

The pressure time relationship in the positive phase are idealised by using a straight line starting with the maximum pressure value but terminating at a time t_d or t_q.

V. CONCLUSION

In the present work we studied to shed light on blast resistant bridge pier theories, the enhancement of building 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.

1. We studied blast mechanism; Different terms related to blast, characteristics of blast etc.
2. Study of different Blast Mitigation Techniques and their applications was studied.
3. We studied analysis of blast resisting bridge pier.

VI. FUTURE SCOPE OF STUDY

1. Cases in which the axial load does not remain constant during the column response time are possible. These include situations where the bomb is located within the structure and the blast excites the girders connected to the column. The effect of this time-varying axial load should be studied.
2. Cases should be studied when the explosions within a structure can cause failure of interior girders, beams and floor slabs.
3. Tests and evaluation of connections under direct blast loads.
4. Tests and design recommendations for base plate configurations and designs to resist direct shear failure at column bases
5. The use of high strength concrete was not very effective as the increase in the ultimate resistance was only 4% for an increase of concrete strength from 4000 psi to 6000 psi.
6. It is important to mention that the strength and stiffness of both concrete and steel is increased by increasing the rate of loading. However, the failure mode will be shifted from a ductile flexural to a brittle shear failure.
7. As for the blast resistant design process for new bridge construction, a preliminary risk assessment should be performed to determine which threats the bridge under

construction may face. The preliminary design of critical bridges should consider both security and redundancy. As the stand-off distance plays a major role, it can be eliminated by including additional planting protective landscaping. Parking spaces beneath critical bridges, as well as access to critical areas such as piers and abutments should be eliminated.

8. It is important to mention that before engineers can begin to design bridges to withstand blast loads, they need to develop an understanding of the principles of blast wave propagation and its potential effects on bridge structures.
9. This research was based on blast loads due to low and intermediate pressures; therefore, further research needs to be done to take into consideration blast loads due to high pressures. Additional research is needed to further develop the proposed blast-resistant design guidelines for critical bridges. Moreover, research is needed to improve the structural response and to mitigate the consequence of an attack.

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