Performance of Box Girder under Blast Load

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Abstract- The increase in the number of terrorist attacks especially in the last few years has shown that the effect of blast Loads on structures is a serious matter that should be taken into consideration in the design process. Although these kinds of attacks are exceptional cases, man-made disasters; blast Loads are in fact dynamic Loads that need to be carefully calculated just like earthquake and wind Loads.

The objective is to study the Box Girder under Blast Resistant Bridge design theories, the enhancement of Bridge security against the effects of explosives in architectural and Structural design process and the design techniques that should be carried out. Firstly, explosives and explosion types have been explained briefly. In addition, the general aspects of explosion process have been presented to clarify the effects of explosives on Bridges and buildings. Better understanding of explosives and characteristics of explosions will enable us to make blast resistant building and bridge design much more efficiently. The effects of blast Load on Box girder for different Load cases are studied.

Keywords – Terrorism, Blast, Explosion, Box Girder Bridge Analysis

I. INTRODUCTION

[1] The events of September 11, 2001, dramatically illustrated the catastrophic damage that terrorists can inflict on our civil structures. The attacks against the World Trade Center and Pentagon, unfortunately, were not isolated incidences of terrorist actions taken against U.S. assets. Over the last several decades there have been an increasing number of terrorist attacks that have led to tremendous losses. As a result of these events, the engineering community has become more aware of the need to design structures that can better withstand the effects of bomb blasts. For example, lessons learned from the Oklahoma City bombing in 1995 and the embassy attacks in Tanzania and Nairobi in 1998 have begun to shape current design guidelines for the prevention of progressive collapse.

During their lifetime, civil engineering structures could be subjected to natural hazards (Earthquakes, hurricanes, tornadoes, floods and fires) or manmade hazards (Blast and impact). Structures are not usually designed for extreme Loadings and when such events occur can lead to catastrophic failure. In recent times, events such as Earthquakes (Strong tremors rocked large parts of north India, including New Delhi and its adjoining areas following a massive 7.8 magnitude earthquake on the Pakistan-Iran border on Tuesday, April 16, 2013) or Terrorist attacks (1995 Murrah Federal building bombing Fig. 1-1, 2001 attack on the World Trade Center Fig. 1-2, and November 26, 2008 Mumbai Terror Attacks Fig. 1-3) have led to structural failures and collapse resulting in related loss of life and staggering economic loss.

Figure 1-1 Alfred P. Murrah Federal Building Before and after Explosion

Figure 1-2 World Trade Center (WTC) Towers Before and after Explosion

Figure 1-3 Taj Hotel Before and after Explosion

The main target of this study is to provide guidance to engineers where there is a necessity of protection against the explosions caused by detonation of high explosives. The guidance describes measures for mitigating the effects of explosions, therefore providing protection for human, structure and the valuable equipment inside. The present work includes information about explosives, blast loading parameters and enhancements for blast resistant bridge design structural approach. Only explosions caused by high explosives (chemical reactions) are considered within the study. High explosives are solid in form and are commonly termed condensed explosives. TNT (trinitrotoluene) is the most widely known example. There are 3 kinds of explosions which are unconfined explosions, confined explosions and explosions caused by explosives attached to the structure.

Bridges in India generally we design for Dead Load, Live Load and Seismic force only. As per IRC Guidelines none of the bridges are checked for Blast Load. In the present paper we are considering as per AASHTO and NCHRP, the ready constructed Box Girder for Blast Load checking. The intent of this research is to investigate Analysis of Box Girder under typical blast loading that will help determine necessary structural design criteria to reduce the probability of catastrophic structural damage, which in turn will lessen human casualties, economic losses and socio-political damage.

The IRC have probability based design methodology and Load factors to be considered while designing bridge against ship impact and vehicular collision. It also has definite criteria to design bridges in different seismic zones with different acceleration coefficients. But it has no specific guidelines to design concrete bridge that will be able to resist typical explosion. [1] National Cooperative Highway Research Program (NCHRP) has invited paper proposals to conduct research in order to develop design and detailing guidelines for blast-resistant highway bridges that can be adopted in the AASHTO manual on bridge design (NCHRP 2004).

II. MODEL BRIDGE

For simplicity and being the most common among the India bridges, a Box Girder of span length 40m was selected for this thesis. Span lengths for Box Girder in India typically vary from 40 to 80m. The corresponding range of span lengths for each type of Box girder Fig. 2-1 illustrates cross-sectional dimensions of Box Girder. For the model bridge, 40m span length was chosen to represent the most common span length for Box Girder. Width of the bridge was selected based on average annual daily traffic (AADT), design speed and other relevant requirements. The model bridge for this thesis was assumed to be of three lane clear width of carriage way 12.0m

Because of the application limitations in the structural analysis software STAAD. Pro, the centerline of each bridge element was modeled. The equivalent area of the girder and the barriers were used in the analysis in finding applied moments and shear forces. Generally, the shape of the structure does not interfere with calculating the applied Loads on the structure. The self-weight of the elements depends only on the cross-sectional area magnitudes.

All static blast Loads were converted to equivalent uniformly distributed Loads and applied at the centerline of each bridge element, which also did not affect the analysis.

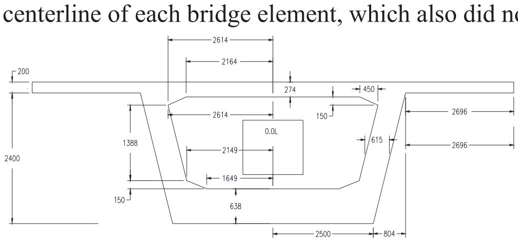


Fig. 2-1 Cross section at support

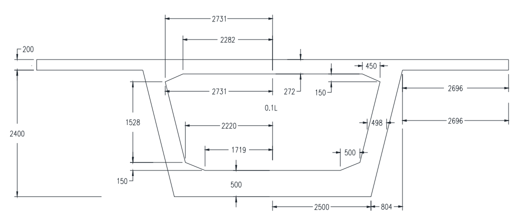


Fig. 2-2 Cross section at mid span

III. BLAST LOAD

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 (msec) 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 Analysis of bridges under explosion, issues that demand attention include energy absorption, safety factors, limit states, Load combinations, resistance functions, structural Analysis 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 (DOD, TR-62, 1976 ie.,U.S Department of Defense Definition of Terrorism).

3.1 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 the TM 5-1300 Manual, Structures to Resist the Effects of Accidental Explosions, developed by the US Department of Defense in December 1990 (DOD 1990), an empirical formula, as shown in equaction-1, was used 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 empirical formula to find the scaled distance, Z (m), is:

$$Z = \frac{R}{W^{\left(\frac{1}{3}\right)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where, R = Distance of target from point of explosion (m), and
W = Equivalent TNT weight of charge (kg).

Finding the scaled distance, Z, using the above formula for known values of R and W, amount of blast pressure can be determined from the chart showing the variation of blast pressure with scaled distance. Using this formula and the chart in TM 5-1300, Applied Research Associates, Inc (ARA, Inc) developed a computer program named ATBlast to calculate the blast Loads for known values of charge weight and standoff distance. The ATBlast software is widely used and recommended by the professionals to determine the equivalent blast pressure due to an explosion. In fact, ATBlast was developed for the US General services Administration (GSA). Alex Remennikov, University of Wollongong, Australia, recommended ATBlast to evaluate blast Load on structures (Remennikov 2004). Justin Domire of Pennsylvania State University used ATBlast to determine blast pressure to redesign the Silver Spring District Courthouse against blast loading (Domire 2003). Therefore, use of ATBlast software to determine blast pressure on the bridge is acceptable.

I have done only for Global Effects, local effects are not considered.

Table 3-1 Equivalent Static Parameters for 500 lb (227 kg) of TNT Explosion

Blast pressure (kN/m2) from 0.9m to 7.5m range

Range (m)	Pressure (kPa)
0.90	25125
1.20	17575
1.51	13154
1.81	10310
2.12	8339
2.42	6892
2.73	5785
3.03	4914
3.34	4213
3.64	3639

3.95	3165
4.25	2768
4.56	2433
4.86	2149
5.17	1907
5.47	1699
5.78	1520
6.08	1365
6.39	1230
6.69	1112
7.00	1009
7.30	918
7.50	865

In order to simplify the method of blast distribution, it was assumed that the blast pressure beyond this region, which diminishes with the distance, has negligible impact on the structure. Weighted average of the vertical components of these inclined pressures on each girder was calculated according to the distribution shown in Fig. 3-1. The highest Load travels the shortest distance, and is perpendicular to the surface. In this case, the highest Load is 10310 kPa generated due to an explosion of 500 lb of TNT (227 kg of TNT) of TNT at a height of 1.8 m above the deck. Box girder, directly under the point of explosion, experiences the highest average pressure of 5155 kPa for a length of 6.0 m, which is approximately 50 percent of the peak pressure of 10310 kPa. These assumptions, named herein as 50 Percent Distribution Rule, respectively, were verified for explosions 500 lb of TNT (227 kg of TNT), and were used in applying average blast pressure for different Loads cases on the bridge components.

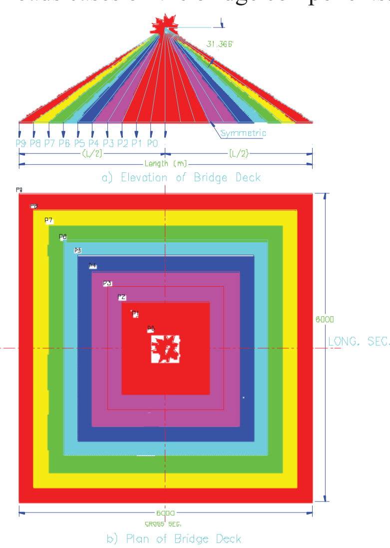


Fig. 3-1 Plan and Elevation of Blast pressure of distribution on Bridge Deck

3.2 Blast Load cases

The typical amount of TNT explosive, used in the ATBlast software to generate the equivalent static Loads, was 500 lb of TNT (227 kg of TNT), as recommended by the AASHTO Blue Ribbon Panel. The explosive Loads were considered as extreme event Loads for which the Load factor is 1.00 according to the AASHTO LRFD Bridge Design Specifications (AASHTO 2003). In addition to these blast Loads, self-weight of the structure was also considered and multiplied by a factor of 1.25. The AASHTO LRFD combination of dead and live Loads for extreme event cases are presented in Eq. 2. The truck live Load was not considered in the analysis for simplicity and because of its effect is negligible compared to that of the blast Load.

WT = 1.25 x DL + 0.50 x LL + 1.00 x EV - (2)

Where, WT = Total Load, DL = Dead Load, LL = Truck LL, and EV = Extreme event Load.

CASE-1 = 1.25x (DL + SIDL) + 0.5 x LL – (3)

CASE-2 = 1*BLAST LOAD – (4)

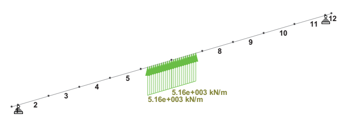
It was further assumed that the blast force projects at maximum angle of approximately 30 degree with the horizontal. Converted blast pressures, as presented in Table 3-1, were categorized into Load cases depending on the location of blast, intensity and the amount applied on a specific area. The model bridge was analyzed using the STAAD. Pro software with 4 separate blast Load cases applied at 4 different critical locations. The blast pressures were converted into uniformly distributed Loads and applied along the centerline of the members for ease of Load application on the model. The tributary distribution of blast pressures, a widely accepted method of converting pressures into uniformly distributed Loads, was applied herein. The various Load cases, formed by these uniformly distributed Loads, are presented in the following sections, and summarized in Table 3-3.

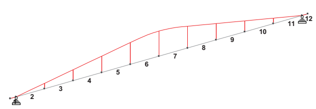
Table 3-2 Various Load Cases

Load Case	Location	Member Affected	Blast Set - backs
CASE 1	Under the Bridge, at Mid-span.	Box Girder	0.9 m above ground.
CASE 2	Over the bridge, at Mid-span.		1.8 m above top slab
CASE 3	Over the bridge, over support.		1.8 m above top slab
CASE 4	Over the bridge, at span end.		1.8 m above top slab

3.2.1. *Load case - 1*

Case 1 blast Load, as shown in Fig. 3-2, was defined for an explosion occurring in the middle of the girder at 0.9m below the deck slab. Due to this explosion, it was assumed that a 6.0 m by 6.0 m square portion of the slab experiences a vertically upward pressure, considering the 30° angle of projection. The center line of girder at mid span is affected as a result of this explosion. This pressure is distributed over the girder along the centerline of girders using 50 percent Distribution rule established in section 3.3.1. Using the tributary area method and the distribution rule, 0.5L is subjected to a pressure of 10310 kPa (Table 4-1). After converting these pressures acting on a 6.0 m width of the deck, the uniformly distributed Load per linear meter along the centerline of the girders was calculated as 5156 kN/m upward Load 0.5L. In the STAAD PRO model, uniformly distributed Loads of 5156 kN/m were applied below box girder was considered.





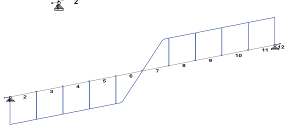
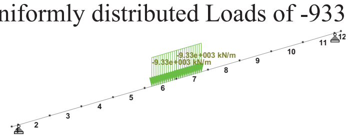


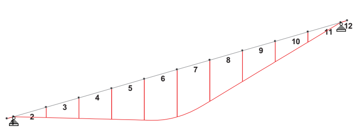
Fig. 3-2 Case 1 Load Fig. 3-3 BM for Case 1 Fig. 3-4 SFD for Case 1

The moment and shear force diagrams produced by these Load are presented in Fig.3-3 and 3-4, respectively. Because of this pattern of blast Loading, the maximum positive moment and shear force on box girder 0.5L are 273784 kNm and -15468 kN, respectively.

3.2.2. *Load case – 2*

Case - 2 blast Load, as shown in Fig. 3-5, was defined for an explosion occurring in the middle of the girder at 1.8 m above the deck slab. Due to this explosion, it was assumed that a 6.0 m by 6.0 m square portion of the slab experiences a vertically downward pressure, considering the 30° angle of projection. The center line of girder at mid span is affected as a result of this explosion. This pressure is distributed over the girder along the centerline of girders using 50 percent Distribution rule. Using the tributary area method and the distribution rule, 0.5L is subjected to a pressure of 10310 kPa (Table 4-2). After converting these pressures acting on a 6.0 m width of the deck, the uniformly distributed Load per linear meter along the centerline of the girders was calculated as -9331 kN/m downward Loads 0.5L. in the STAAD PRO model, uniformly distributed Loads of -9331 kN/m were applied above box girder was considered.





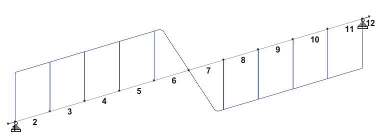
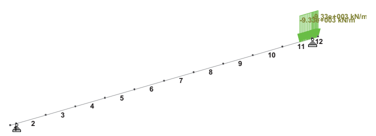


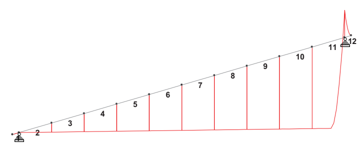
Fig. 3-5 Case 2 Load Fig. 3-6 BM Fig. 3-7 SFD

The moment and shear force diagrams produced by these Load are presented in Fig. 3-6 and 3-7, respectively. Because of this pattern of blast loading, the maximum negative moment and shear force on box girder 0.5L are -495473 kNm and 27993 kN, respectively.

3.2.3. *Load case – 3*

Case - 3 blast Load, as shown in Fig. 3-8, was defined for an explosion occurring on the right side at support of the girder at 1.8 m above the deck slab. Due to this explosion, it was assumed that a 6.0 m by 6.0 m square portion of the slab experiences a vertically downward pressure, considering the 30° angle of projection. The center line of girder at mid span is affected as a result of this explosion. This pressure is distributed over the girder along the centerline of girders using 50 percent Distribution rule established in section 3.1. Using the tributary area method and the distribution rule, 0.5L is subjected to a pressure of 10310 kPa (Table 4-3). After converting these pressures acting on a 6.0 m width of the deck, the uniformly distributed Load per linear meter along the centerline of the girders was calculated as -9331 kN/m downward Loads 0.5L. in the STAAD PRO model, uniformly distributed Loads of -9331 kN/m were applied below box girder was considered.





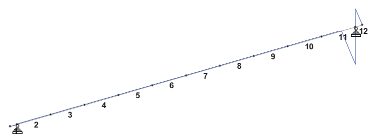
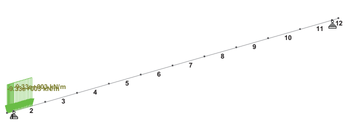


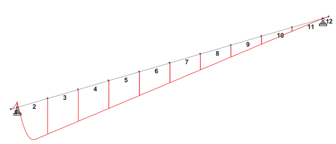
Fig. 3-8 Case 3 Fig. 3-9 BM Fig. 3-10 SF

The moment and shear force diagrams produced by these Load are presented in Fig. 3-9 and 3-10, respectively. Because of this pattern of blast loading, the maximum negative moment and shear force on box girder 0.5L are -4703 kNm and 245 kN, respectively.

3.2.4. *Load case – 4*

Case - 4 blast Load, as shown in Fig. 3-11, was defined for an explosion occurring in the left side at support of the girder at 1.8 m above the deck slab. Due to this explosion, it was assumed that a 6.0 m by 6.0 m square portion of the slab experiences a vertically downward pressure, considering the 30° angle of projection. The center line of girder at mid span is affected as a result of this explosion. This pressure is distributed over the girder along the centerline of girders using 50 percent Distribution rule established in section 3.1. Using the tributary area method and the distribution rule, 0.5L is subjected to a pressure of 10310 kPa (Table 4-4). After converting these pressures acting on a 6.0 m width of the deck, the uniformly distributed Load per linear meter along the centerline of the girders was calculated as -9331 kN/m downward Load 0.5L. in the staad pro model, uniformly distributed Loads of -9331 kN/m were applied above box girder was considered.





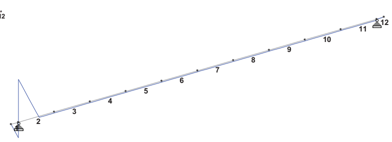


Fig. 3-11 Case 4 Fig. 3-12BM Fig. 3-13 SF

The moment and shear force diagrams produced by these Load are presented in Fig. 3-12 and 3-13, respectively. Because of this pattern of blast loading, the maximum negative moment and shear force on box girder 0.5L are -10077 kNm and -525 kN, respectively.

IV. Model bridge Analysis

4.1. *Bridge Analysis under Blast Load*

From the STAAD output, the applied moments and shear forces on the critical elements of the bridge were determined, and compared with their respective capacity to assess their Analysis.

The Analysis was measured by comparing the applied moments and shear forces with the respective capacity of the members. As a general rule of analysis, if the applied Load exceeds member capacity, the member can be considered as failed. The maximum applied moments, shears and the capacity of each critical member under consideration were tabulated in the member status tables with their respective survival or failure conditions.

After determining the effect of 500 lb of TNT (227 kg of TNT) explosion on the structure, several further analyses of the model bridge were performed to determine the amount of TNT the respective members could resist before failure. The amount varied depending on the standoff distance of the explosion, member type and the location of the explosion. The maximum amount of blast Loads, which the Box Girder, can resist before failure, were determined by using trial and error method. Several scenarios of blast Loading were considered to find these Loads for each individual case.

4.1.1. *Analysis under case-1 blast Load*

Table 4-1 shows the condition of the model bridge components Case -1 explosion at 0.9 m height below the bridge deck at mid-span. Due to this type of explosion, Box girder in length of span, collapsed. Very high positive moments and shears, generated because of this explosion, caused complete failure of all the members. The moments and shear forces are far beyond their capacity. As a result of Case -1 blast Loads, the model bridge will completely collapse and will require immediate replacement.

Table 4-1 Performance of Box Girder_ Case – 1

Member	Bending Moment kNm		Shear Force kN		Moment Failure	Shear Failure
	Capacity	Applied	Capacity	Applied		
0.0L	-50	0	5831	-15468	TRUE	FALSE
0.1L	-15190	59397	3372	-15468	FALSE	FALSE
0.2L	-26544	118794	2428	-15468	FALSE	FALSE
0.3L	-34724	178191	1716	-15468	FALSE	FALSE
0.4L	-39707	237589	1150	-15468	FALSE	FALSE
0.5L	-41510	273784	16	0	FALSE	TRUE

4.1.2. *Analysis under case-2 blast Load*

Table 4-2 shows the condition of the model bridge components after Case 2 explosion at 1.8 m height above the bridge deck at mid-span. Due to this type of explosion, Box girder in length of span, collapsed. Very high moments and shears, generated because of this explosion, caused complete failure of all the members. The moments and shear forces are far beyond their capacity. As a result of Case 2 blast Loads, the model bridge will completely collapse and will require immediate replacement.

Table 4-2 Performance of Box Girder_ Case – 2

Member	Bending Moment kNm		Shear Force kN		Moment Failure	Shear Failure
	Capacity	Applied	Capacity	Applied		
0.0L	-50	0	5831	27993	TRUE	FALSE
0.1L	-15190	-107493	3372	27993	FALSE	FALSE
0.2L	-26544	-214986	2428	27993	FALSE	FALSE
0.3L	-34724	-322479	1716	27993	FALSE	FALSE
0.4L	-39707	-429973	1150	27993	FALSE	FALSE
0.5L	-41510	-495476	16	0	FALSE	TRUE

4.1.3. *Analysis under case-3 blast Load*

Table 4-3 shows the condition of the model bridge components after Case -3 explosions at 1.8 m height above the bridge deck at right side at support. Due to this type of explosion, Box girder in length of span is safe. Very low moments and shears are generated because of this explosion. All members are safe. As a result of Case -3 blast Loads, the model bridge is completely safe.

Table 4-3 Performance of Box Girder_ Case – 3

Member	Bending Moment kNm		Shear Force kN		Moment Failure	Shear Failure
	Capacity	Applied	Capacity	Applied		
0.0L	-50	0	5831	245	TRUE	TRUE
0.1L	-15190	-941	3372	245	TRUE	TRUE
0.2L	-26544	-1881	2428	245	TRUE	TRUE
0.3L	-34724	-2822	1716	245	TRUE	TRUE
0.4L	-39707	-3762	1150	245	TRUE	TRUE
0.5L	-41510	-4703	16	245	TRUE	FALSE

4.1.4. *Analysis under case-4 blast Load*

Table 4-4 shows the condition of the model bridge components after Case -4 explosions at 1.8 m height above the bridge deck at left side at support to 0.1L. Due to this type of explosion, Box girder in length of span, collapsed. Very high moments and shears, generated because of this explosion, caused complete failure of members 0.0L, 0.1L in bending moment and 0.0L, 0.5L in shear failure. The moments and shear forces are far beyond their capacity. As a result of Case -4 blast Loads, the model bridge will completely collapse.

Table 4-4 Performance of Box Girder_ Case – 4						
Member	Bending Moment kNm		Shear Force kN		Moment Failure	Shear Failure
	Capacity	Applied	Capacity	Applied		
0.0L	-50	2838	5831	20190	FALSE	FALSE
0.1L	-15190	-18139	3372	-525	FALSE	TRUE
0.2L	-26544	-16124	2428	-525	TRUE	TRUE
0.3L	-34724	-14108	1716	-525	TRUE	TRUE
0.4L	-39707	-12093	1150	-525	TRUE	TRUE
0.5L	-41510	-10077	16	-525	TRUE	FALSE

4.2. *Blast capacity of Bridge elements*

Because most of the Load cases considered for 500 lb of TNT (227 kg of TNT) resulted in complete collapse of the model bridge, it may be worthwhile to determine the actual capacity of the bridge components to resist the blast Load. The capacities of components were checked to 1.2 kg of TNT, 1.3 kg of TNT and 5.0 kg of TNT. The results are as below.

4.2.1. *Box Girder capacity resist up to 1.2kg of TNT*

Only Load Cases -1 and case -2 locations were found critical. When the explosion occurs on top of the bridge for Case 2 Loads location, the blast Load produced due to an explosion of only 1.2 kg of TNT (Table 4-5) at 1.8 m above the bridge deck is found to be the maximum blast Load the Box girder could resist before failure. The average pressures due to this explosion are 401 kPa (Table 4-5, using 50 Percent Distribution Rule) on girder 0.5L. The equivalent uniformly distributed Loads are -368 kN/m, respectively, applied along the centerline in the middle 6.0 m width of the girder.

The maximum bending moment produced on girder 0.5L by these Loads is -19541 kNm which is less than its capacity of -41510 kNm. The maximum shear force on the girder due to these Loads is 1104 kN, which is equal to its capacity. Shear capacity controlled the amount of explosive the Box girder could resist before failure in case the explosion occurred on top of the bridge at the girder mid-span. In general, the pre-stressed girders are not designed with much excess capacity beyond the minimum requirement. Therefore, it appears reasonable that the girders can resist pressures caused by 1.2 kg of TNT explosion over the bridge.

Table 4-5 Performance of Box Girder_ Case - 2 (1.2kg of TNT)						
Member	Bending Moment kNm		Shear Force kN		Moment Failure	Shear Failure
	Capacity	Applied	Capacity	Applied		
0.0L	-50	0	5831	1104	TRUE	TRUE
0.1L	-15190	-4239	3372	1104	TRUE	TRUE
0.2L	-26544	-8479	2428	1104	TRUE	TRUE
0.3L	-34724	-12718	1716	1104	TRUE	TRUE
0.4L	-39707	-16957	1150	1104	TRUE	TRUE
0.5L	-41510	-19541	16	0	TRUE	TRUE

4.2.2. *Box Girder capacity resist up to 1.3kg of TNT*

Table 4-6 shows the Load Cases -2 locations were considered herein for the blast capacity (1.3 kg of TNT) analysis of the Box girder. Box girder failure only in shear. The average pressures due to this explosion are 429 kPa (Table 4-6, using 50 Percent Distribution Rule) on girder 0.5L. The equivalent uniformly distributed Loads are -393 kN/m, respectively, applied along the centerline in the middle 6.0 m width of the girder.

The maximum bending moment produced on girder 0.5L by these Loads is -20868 kNm which is less than its capacity of -41510 kNm. The maximum shear force on the girder due to these Loads is 1179 kN, which is marginally more than its capacity. Shear capacity controlled the amount of explosive the Box girder could resist before failure in case the explosion occurred on top of the bridge at the girder mid-span. Therefore, it appears reasonable that the girders can resist pressures caused by 1.3 kg of TNT explosion over the bridge.

Table 4-6 Performance of Box Girder_ Case - 2 (1.3kg of TNT)						
Member	Bending Moment kNm		Shear Force kN		Moment Failure	Shear Failure
	Capacity	Applied	Capacity	Applied		
0.0L	-50	0	5831	1179	TRUE	TRUE
0.1L	-15190	-4527	3372	1179	TRUE	TRUE
0.2L	-26544	-9055	2428	1179	TRUE	TRUE
0.3L	-34724	-13582	1716	1179	TRUE	TRUE
0.4L	-39707	-18109	1150	1179	TRUE	FALSE
0.5L	-41510	-20868	16	0	TRUE	TRUE

4.2.3. *Box Girder capacity cannot resist 5.0kg of TNT*

Table 4-7 shows the Load Cases -2 locations were considered herein for the blast capacity (5.0 kg of TNT) analysis of the Box girder. The average pressures due to this explosion are 1181 kPa (Table 4-7, using 50 Percent Distribution Rule) on girder 0.5L. The equivalent uniformly distributed Loads are -1082 kN/m, respectively, applied along the centerline in the middle 6.0 m width of the girder.

The maximum bending moment produced on girder 0.5L by these Loads is -57454 kNm which is more than its capacity of -41510 kNm. The maximum shear force on the girder due to these Loads is 3246 kN, which is more than its capacity. Therefore, it appears the girders cannot resist pressures caused by 5 kg of TNT explosion over the bridge.

Table 4-7 Performance of Box Girder_ Case - 2 (5kg of TNT)

Member	Bending Moment kNm		Shear Force kN		Moment Failure	Shear Failure
	Capacity	Applied	Capacity	Applied		
0.0L	-50	0	5831	3246	TRUE	TRUE
0.1L	-15190	-12465	3372	3246	TRUE	TRUE
0.2L	-26544	-24929	2428	3246	TRUE	FALSE
0.3L	-34724	-37394	1716	3246	FALSE	FALSE
0.4L	-39707	-49859	1150	3246	FALSE	FALSE
0.5L	-41510	-57454	16	0	FALSE	TRUE

4.2.4. *Experimental validation*

An effort was made to validate the theoretical modeling performed in this present work with available experimental results. An extensive literature review was performed herein for this purpose. The search could not locate any full-scale blast Load test on any bridge structures except for demolition purposes only. Some real life blast tests were conducted on experimental buildings; however, as these data are very sensitive and confidential in nature for security reasons, they are not available to the public. Several attempts were made to legally collect some blast test data in order to validate the ATBlast and STAAD Pro models developed herein, but no viable response was received from these sources.

V. Conclusion

Blast resistant bridge design is considered the most vital work that has not been addressed enough. This thesis may give some important insights about the Analysis of Box Girder. It will also help determine the proper methods of developing blast resistant bridge design in combination with the traditional method.

Based on this Present work, the following conclusions were made:

1. To protect bridges from the act of terrorist explosion, blast resistant bridge design and retrofit techniques should be developed and adopted by the applicable code and regulatory agencies.
2. It was found from the analytical experiments that the model bridge failed due to the typical blast Load generated by an explosion of 226.8 kg of TNT (Trinitrotoluene) and applied over the bridge at girder end or mid-span.
3. Part of the bridge survived the explosion when the typical blast Load was applied at a location close to the girder, which included blast Loads applied directly on span.
4. The model bridge could resist blast pressure generated due to an explosion of 1.2 kg of TNT and 1.3 kg of TNT.
5. The model bridge could not resist blast pressure generated due to an explosion of 5 kg of TNT.
6. It is performed purely for the illustrative purposes and should not be taken as indicator for any kind of terrorist attack. Assumptions were made on the blast Load and its locations. Also the standoff distance plays an important role in protection of the member against the blast.

5.1. *Recommendation and Future research directions*

The research was performed based on the static equivalent of the blast Load, which is a dynamic Load with high impact. It focused on the Analysis of a Box Girder. The bridge Analysis depended on the capacity of the members, amount and magnitude of the blast Load, location of the explosion and the standoff distances. Under the dynamic Loading condition, the results may vary if the structure geometry, member strength, and the magnitude and point of explosion remain the same.

The following are recommendations for Future Research:

1. Pre-stressing of girder only increases its strength against traditional vertically downward Loads. Future work may be undertaken to determine methods of pre-stressing and post-tensioning that will increase positive as well as the negative moment capacity of the girders.

2. The shear strength of the Box girder might be a major concern in developing blast resistant design. It was found from this work that, in some instances, a girder failed due to inadequate shear capacity before it failed because of applied moments. Therefore, more work is necessary to identify method of increasing shear capacity of the Box girder. Parametric work can be conducted by thickening the girder web with varying amount of reinforcements to determine maximum shear capacity.
3. This research was based on the equivalent static Loads for dynamic blast pressures. Finite element model analysis of the entire bridge and its components is recommended to determine Analysis under dynamic Loads using ATBlast.
4. Due to unavailability of real life blast Load test data on structures (because of their sensitivity and confidentiality), experimental validation of the theoretical findings was not possible herein. Validation of the static and dynamic experiments can be achieved by comparing analytical data with the real life data.
5. Standoff distance plays a major role in protecting the structure against failure. Appropriate means and methods of increasing standoff distances are necessary to be developed through further work in order to protect the existing and future bridges from terrorist explosion.

REFERENCES

[1] NCHRP Report 645: Blast-Resistant Highway Bridges: Design and Detailing Guidelines, Project No. 12-72, FY 2005.
[2] Association of State Highway and Officials (AASHTO), Load and Resistant Factor Design, Bridge Design Specifications, 5th Edition, 2010, Cl.3.15 Blast Loading P.No. 157.
[3] The Blue Ribbon Panel on Bridge and Tunnel Security, 2003. Recommendation for Bridge and Tunnel Security. Special report prepared for FHWA and AASHTO, Washington, DC.
[4] TM 5-1300(UFC 3-340-02) U.S.Army Corps of Engineers (1990), "Structures to Resist the Effects of Accidental Explosions", US Army Corps of Engineers, Washington, D.C.
[5] Design of Blast Resistant Buildings in Petrochemical Facilities, ASCE Task committee on Blast Resistant Design, 1997.
[6] Ministry of Road Transport & Highways (2000). Pocket Book for Bridge Engineers (First Revision).
[7] IS_4991_1968: Criteria for Blast Resistant Design of Structures for Explosions above Ground.
[8] Research Engineers International, India, STAAD Pro V8i.
[9] ATBlast software, Developed by Applied Research Associates (ARA), Inc.
[10] IRC_6: Standard Specifications and code of practice for Road Bridges Sec : II, Loads and Stresses.