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Parametric study of RCC bridge superstructure under blast loading

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Abstract—The paper presents the performance of a Reinforced Concrete bridge under blast loading. IRC has specified probability based design methodology and load factors for designing bridge piers against ship impact and vehicular collision. Currently, no specific IRC design guideline exists for bridges against blast loading. Structural engineering methods to protect infrastructure systems from terrorist attacks are required. Bridges are unique in terms of materials used, length, width, skewness, span, loading, traffic conditions, and overall geometry. This paper investigated the most common types of concrete bridges that is the slab on girder bridge. The analysis and design of structures subjected to blast loads require a detailed understanding of blast phenomena and the dynamic response of various structural elements. Blast load was stimulated as a time history load using STAAD Pro. Software. The reinforced concrete bridge was thoroughly investigated and the results provide insightful information regarding the damage.

Keywords— Blast load Analysis, IRC 112:2011, IRC 6:2017, RCC concrete bridge, Time history loading

I. INTRODUCTION

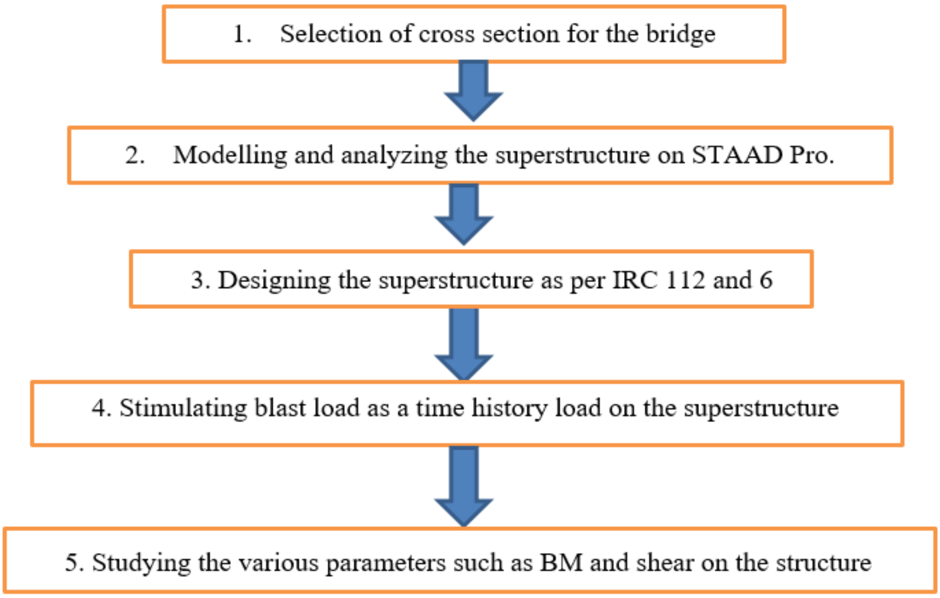
The term blast is commonly used to describe any situation in which the rapid release of energy occurs from a chemical, mechanical or nuclear source. However, from the point of view of the effects of explosions upon structural systems, there exists a set of fundamental characteristics which must be defined and considered, irrespective of the source. Explosions occurring in urban areas or close to facilities such as buildings and protective structures may cause tremendous damage and loss of life. The immediate effects of such explosions are blast overpressures propagating through the atmosphere, fragments generated by the explosion and ground shock loads resulting from the energy imparted to the ground. Conventional buildings are constructed quite differently than hardened military structures and as such are generally quite vulnerable to blast and ballistic threats. In order to design structures which are able to withstand explosions it is necessary to first quantify the effects of such explosions. Typically, it takes a combination of specialist expertise, experimental tests, and analysis tools to properly quantify the effects. With this in mind, developers, architects and engineers increasingly are seeking solutions for potential blast situations, to protect building occupants and the structures. Terrorism presents a real threat to all aspects of society. The terrorist attacks of September 11, 2001 have shown how devastating a successfully implemented attack can be to the United States. Homeland security has become a priority, one that government officials and civilians alike cannot take lightly.

In the past few years, the vulnerability of transportation infrastructure to terrorism has become evident. The casual observer might think that since most of the U.S. highway system has a natural redundancy, it is not susceptible to an attack. However, this is not the case. Transportation facilities are attractive targets for terrorists because they are easily accessible, and an attack could have considerable impact on human lives and economic activity. This is especially true for transportation assets such as bridges, which carry traffic through highway network meeting points, and where alternate routes are not available because of geographic constraints.

Terrorist threats have targeted the Golden Gate Bridge and the Brooklyn Bridge. Bridges such as these not only provide transportation connecting two regions, but they also serve as national landmarks. A successful attack would disrupt regional traffic and have severe economic consequences.

II. METHODOLOGY

The RCC slab on girder bridge is analysed in this project by using software. The software used in this thesis is STAAD Pro. For both longitudinal and transverse analysis. The analysis and design of the superstructure is based on IRC-112:2011 and load calculation is based on IRC-6:2017. The following diagram shows the typical methodology adopted in the project



III. BLAST WAVE PHENOMENON

The violent release of energy from a detonation converts the explosive material into a very high pressure gas at very high temperatures. A pressure front associated with the high pressure gas propagates radially into the surrounding atmosphere as a strong shock wave, driven and supported by the hot gases. The shock front, termed the blast wave, is characterized by an almost instantaneous rise from ambient pressure to a peak incident pressure Pso. This pressure increase or shock front travels radially from the burst point with a diminishing shock velocity U, which is always in excess of the sonic velocity of the medium. Gas molecules behind the front move at lower flow velocities, termed particle velocities u. These latter particle velocities are associated with the dynamic pressures formed by the winds from the passage of the shock front, which have a maximum pressure, qo. As the shock front expands into increasingly larger volumes of the medium, the peak incident pressures at the fronts decrease and the durations of the pressures increase.

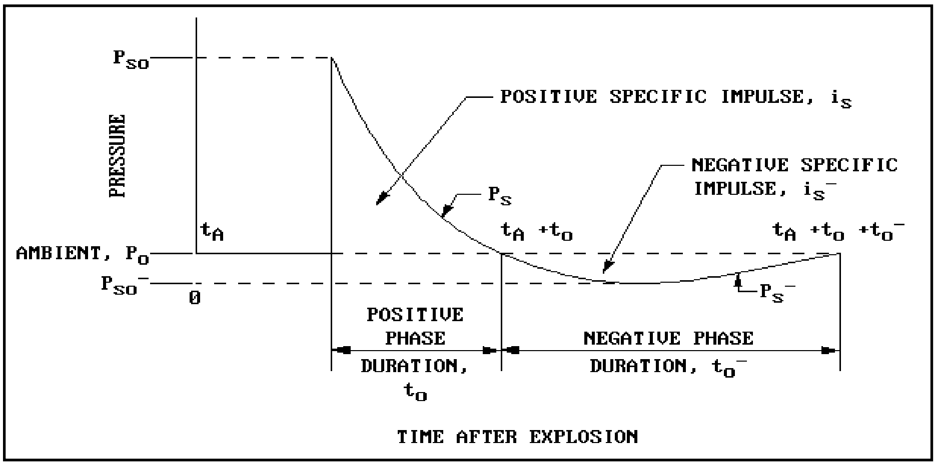
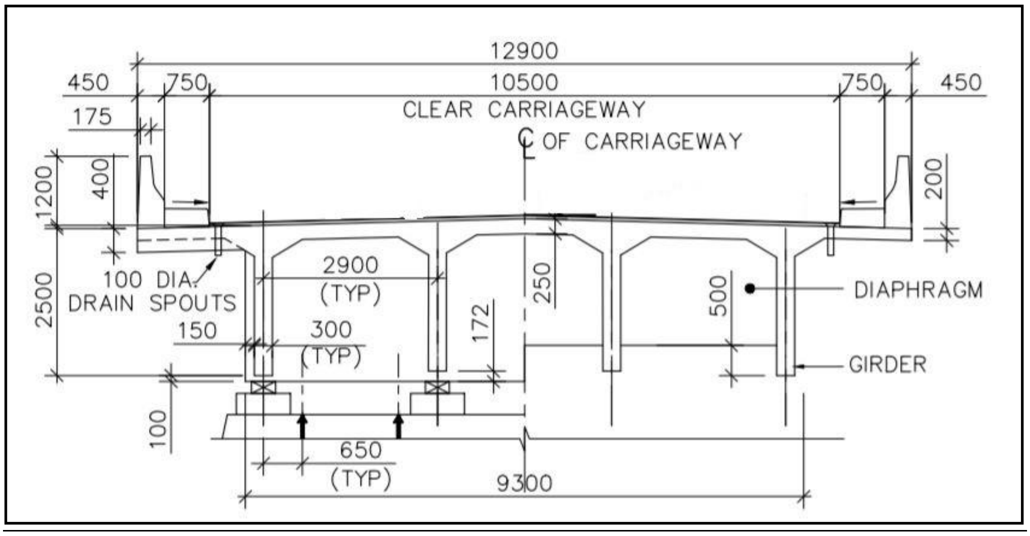


Figure 1 Free-field pressure-time variation

At any point away from the burst, the pressure disturbance has the shape shown in Figure 1. The shock front arrives at a given location at time tA and, after the rise to the peak value, Pso the incident pressure decays to the ambient value in time to which is the positive phase duration. This is followed by a negative phase with a duration to- that is usually much longer than the positive phase and characterized by a negative pressure (below ambient pressure) having a maximum value of Pso-, as well as a reversal of the particle flow. The negative phase is usually less important in a design than is the positive phase, and its amplitude Ps- must, in all cases, be less than ambient atmosphere pressure po. The incident impulse associated with the blast wave is the integrated area under the pressure-time curve and is denoted as is for the positive phase and is- for the negative phase. An additional parameter of the blast wave, the wave length, is sometimes required in the analysis of structures. The positive wave length Lw+ is that length at a given distance from the detonation which, at a particular instant of time, is experiencing positive pressure. The negative wave length Lw- is similarly defined for negative pressures.

IV. RCC BRIDGE MODEL

For this research a bridge of span 25m and deck width of 12.9m is considered. It is RCC Tee girder on RCC slab bridge. The typical cross section of the bridge is shown below in figure



The superstructure is designed for following types of loads

a. Self-weight of the girder and deck slab

b. Crash Barrier and raised safety kerb

c. Wearing coat

d. Vehicular live load as per IRC 6 – 2017

1) Class-A-1 lane/2 lanes/3lanes

2) Class 70R 1 lane+ Class A-1 lane

Materials used were M35 concrete and Fe500 steel

Design of Girder

Main reinforcement details:

Location	Diameter of bar	Number of Layers	Number of bars
At Mid-Span	32	5	15
At support	32	3	8

Shear reinforcement details:

Location	Type of stirrups	Diameter of stirrups	Spacing
At Mid-Span	2 legged	10	300
At support	2 legged	10	200

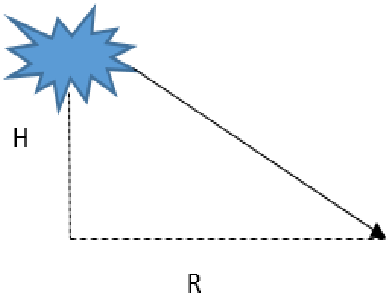
Design of Deck Slab

Location	Type of Reinforcement	Diameter (mm)	Spacing (mm c/c)
Mid-Span	Main	25	300
	Distribution	12	130
Support	Main	25	160
	Distribution	12	185

V. EQUIVALENT BLAST LOADS

The method to determine the explosion load is a complex phenomenon as the explosion load diminishes with the distance from the point of explosion. The amount of explosion pressure generated is inversely proportional to the scaled distance.

Blue Ribbon Panel (BRP) of bridge and tunnel experts from professional practice, academia, federal and state agencies, and toll authorities convened 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 (AASHTO), acknowledges that the nation's bridges and tunnels are vulnerable to terrorist attacks. From Table 3 of the BRP Report, the highest possibility of a conventional car bomb is with an amount of 500 pound i.e. 226.8kg of trinitrotoluene (TNT) explosive. This amount of TNT is used for the project work. Assuming the bomb is carried in a car trunk or on a truck bed, it is approximated that the explosion centroid occurs at 1.22 m above the bridge deck, and is designated as 'H'. The distance in the plane of the bridge deck of the point of interest from the explosion is designated as 'R'.



The empirical formula to find the scaled distance, Z as mentioned in UFC 3-340-02 (STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS) given by

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

Using this formula and graph given in UFC 3-340-02, the explosion loads for known values of charge weights and the standoff distances can be calculated. The explosion load for 226.8kg of TNT is converted into equivalent load is presented in the table 1

STAND OFF (METER)	SCALED DIST (Z)	PRESSURE (KPA)	TOA (sec)	TD (sec)	IMPULSE (kPA-ms)
1.22	0.50	17487.0488	0.001484219	0.00148	2277.84571
1.26	0.52	16638.4762	0.00146517	0.00147	2138.51958
1.39	0.56	15133.7569	0.001430247	0.00143	1908.16703
1.66	0.63	12990.1208	0.001388975	0.00139	1618.91505
2.05	0.71	11094.9099	0.00136437	0.00136	1401.94820
2.54	0.81	9289.04125	0.00134929	0.00135	1231.53376
3.11	0.91	7905.6904	0.001373895	0.00137	1127.77677
3.75	1.02	6715.39696	0.00142866	0.00143	1060.51776
4.46	1.13	5769.32833	0.001531841	0.00153	1025.54963
5.21	1.24	5000.97627	0.001674707	0.00167	1011.89020
6.01	1.36	4314.29747	0.00190488	0.00190	1015.60557
6.86	1.47	3791.61468	0.002182675	0.00218	1031.01340

Table 1 Blast Load Parameters for 1 foot i.e. 0.3 m increment

As the explosion magnitude increases, the influence surface increases. This idea must be balanced with the fact that after a certain distance, the blast wave has little effect. In addition, since explosion loads in this study are manually applied on member, a reasonable cutoff criterion is necessary. Explosion loads are applied as time history varying impulse of triangular nature.

The peak pressure has been converted into equivalent force considering the tributary area.

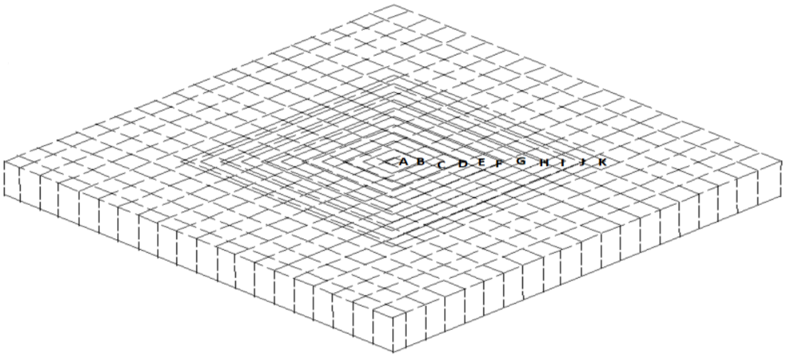


Figure 2 Typical contours of peak pressure from charge location

Contour	Ta (sec)	Td (sec)	Explosion wave location (m)	Load (kN)
A	0.00148421	0.00148	0	1573.834
B	0.00146517	0.00147	0.3	1497.463
C	0.00143024	0.00143	0.6	1447.166
D	0.00138897	0.00139	0.9	1558.815
E	0.00136437	0.00136	1.2	1529.017
F	0.00134929	0.00135	1.5	1504.825
G	0.00137389	0.00137	1.8	1437.847
H	0.00142866	0.00143	2.1	1381.453
I	0.00153184	0.00153	2.4	1306.212
J	0.00167470	0.00167	2.7	1250.244
K	0.00190488	0.00190	3	1169.714

Table 2 Equivalent time history blast loads at different location

VI. RESULTS

Member	**Bending Moment (KNm)**		**Shear Force (KN)**	
	Capacity	Applied	Capacity	Applied
GIRDER 1	12241	8657	1826.96	2191
GIRDER 2	12241	12123.78	1826.96	2993.75
GIRDER 3	12241	12196.62	1826.96	2914.8
GIRDER 4	12241	8007.26	1826.96	2216.87

Table no 3 Results when subjected to blast load at mid span (with internal diaphragm)

Member	**Bending Moment (KNm)**		**Shear Force (KN)**	
	Capacity	Applied	Capacity	Applied
GIRDER 1	12241	6364.92	1826.96	1207.96
GIRDER 2	12241	5885.09	1826.96	1139.62
GIRDER 3	12241	5885.09	1826.96	1139.62
GIRDER 4	12241	6364.92	1826.96	1207.96

Table no 4 Results when subjected to blast load at support (with internal diaphragm)

It was observed that maximum forces were attracted by the internal diaphragm. So in the next case internal diaphragm were removed.

Member	**Bending Moment (KN-m)**		**Shear Force (KN)**	
	Capacity	Applied	Capacity	Applied
GIRDER 1	12241	5343	1826.96	702.64
GIRDER 2	12241	10462.08	1826.96	1680.44
GIRDER 3	12241	10405.87	1826.96	1642.82
GIRDER 4	12241	5334.6	1826.96	880..47

Table no 5 Results when subjected to blast load at mid span (without internal diaphragm)

Member	**Bending Moment (KNm)**		**Shear Force (KN)**	
	Capacity	Applied	Capacity	Applied
GIRDER 1	12241	6364.92	1826.96	1207.96
GIRDER 2	12241	5885.09	1826.96	1139.62
GIRDER 3	12241	5885.09	1826.96	1139.62
GIRDER 4	12241	6364.92	1826.96	1207.96

Table no 6 Results when subjected to blast load at support (without internal diaphragm)

VII. CONCLUSION

- To protect bridges from the act of terrorist explosion, blast resistant bridge design and retrofit techniques should be developed, and adopted by the applicable codes and regulatory agencies
- The bridge has been designed as per IRC code
- Assumptions were made on the explosion load and its location. Also standoff distance plays an important role in protection of the member against the explosion
- The blast load analysis when carried out in STAAD will basically allow the researcher to determine the effect of explosion on bridge under time history analysis.
- Two explosion cases at the mid-span and at the support are investigated.
- The explosion case that were applied at the centre that consist of internal diaphragm had more severe affects in terms of moment capacity and shear
- The bridge survived the explosion when the typical blast load was applied under following cases
  1) When blast load was applied at support
  2) When the bridge does not consist of internal diaphragm
- When designing for blast load curtailment of reinforcement should not be done

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