The Effect of Dead, Live and Blast Loads on a Suspension Bridge

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ABSTRACT

Bridges in America are of special importance. The analysis of these bridges should be carried out for different loading conditions. Bridges are normally designed for dead load, live load and other occasional loads. American Association of State Highways and Transportation Officials (AASHTO) have specified for the ship impact, seismic vulnerability and also against vehicular collisions. But there are no definite structural design criteria for the bridges under typical blast loadings. This thesis is intended to provide a basic guideline for using the blast load analysis on the suspension bridge. Further research may be carried out in this field to develop some standards for the bridge resistance against explosions. Also, the AASHTO loading was applied to study the effect of live load on the bridge. The results obtained from live loading on the same suspension bridge were implemented to allocate costs depending upon the effect of particular vehicle on the bridge deck. When compared with the data available through the State Road Commission, State of Maryland. Results presented in this thesis hence demonstrate as significant potential for using the RM BRIDGE and for thorough investigation of the vehicle-bridge interaction and dynamic loading on bridges. For carrying out the impact of blast loading, the bridge was modeled in parallel using the STADD PRO V8i system. The whole modeling of the suspension part of the bay bridge was done on the STADD PRO V8i for carrying out the non-linear analysis of the blast loads. The behaviors of each element under the effect of the blasts were studied from the output generated by the STADD PRO V8i.The output of the software presents results including moments, axial loads anddisplacementsMoreover,momentsandaxialloadateachnodeandatanypoint within the element, can be easily obtained from the software output.

KEY WORDS: Bridges, loading, conditions.

1. INTRODUCTION

Bridge response induced by moving vehicles is an important aspect in the design and structural evaluation of bridges. There are quite some phenomena that influence the bridge's behavior. For the better understanding of the suspension bridge, different theories have been discussed here like, The Rankine Theory, The Elastic Theory, The Deflection Theory, and also The Linearized Deflection Theory.

Problem statement: American Association of State Highways and Transportation Officials (AASHTO) have design methodologies for the ship impact, seismic vulnerability and also against vehicular collisions. But there are no definite structural design criteria for the bridges under typical blast loadings. The intent of this research is to carry out the dead, live and blast load analysis on a suspension part of William Preston lane Jr.Memorial Bridge.

Description of the Model Bridge: The Chesapeake Bay Bridge, also simply known as the Bay Bridge (officially known as William Preston Lane, Jr.Memorial Bridge) is located in Mary land, which spans the Chesapeake Bay and connects the state's Eastern and Western Shore regions of Maryland. The bridge actually comprises of twobridgebounds, namely, the east bound bridge and the west bound bridge, and the former was built in 1952, while the latter was built in 1973.With the total length of 6.9km and 7km, the bridges are the longest in the state of Maryland and are also among the world's longest and most-scenic over- water structures. The center suspension span on the east bound bridge is 480m in length with a maximum clearance of 55.8 m. The side spans are of 202.5 m. The maximum elevation for the cables is about 53.319m.

Suspension Bridge:

Historic Background: The idea of suspension bridge was first suggested by nature to the extra vagancies of ropes of creepers, vines and other trailing plants in the warm countries. It was a bridge created by primitive man, found in South East Asia, South America and Equatorial Africa.

Components of Suspension bridge: A suspension bridge is mainly divided into two categories, superstructure and substructure. Bridge deck, cables, hangers, main supporting system, lateral bracing and tower (above bridge deck) are included in superstructure, whereas foundation, anchorages, pier caps and columns falls under substructure. Suspension bridge are in compression where as the cables and hangers are the members in compression as shown in Figure 2.

The Linearised Deflection Theory: In 1894, Godard proposed a linearization of the theory both for the simplification and for the advantages of the non-linear character reflection theory that it gave by making legitimate the use of superposition and influence lines.

Figure 1. William Preston Lane, Jr. Memorial Bridge

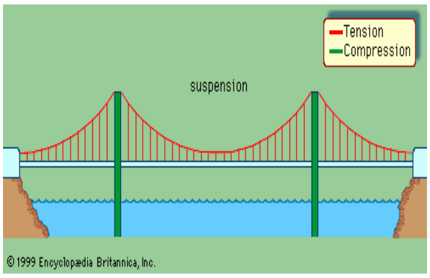

Figure2 Members of a suspension bridge

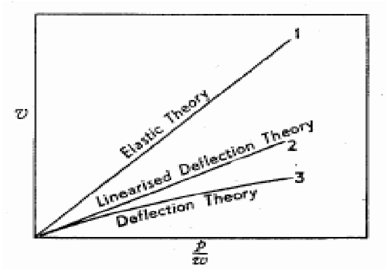

Figure 3. Comparison between different theories

There are number of ways in which the above theory can now be developed. They are: a) Tie Analog Method, b) Energy Method, c) Flexibility Co-efficient Method.

Dead load, Live load and Blast loads:

Dead load: The dead load includes the weight of all components of the structure, appurtenances and utilities attached, earth cover, wearing surface, future overlays and planned widening. The model suspension bridge is a huge complex structure. The bridge deck, stringers, diaphragm and the connections are not modeled for simplicity.

Vehicular Live Load: Generally the number of design lanes should be determined by taking integer part of ratio*w* /12 where *w* is clear roadway width in feet. Incases, where the traffic lanes are less than 12 ft., the number of design lanes should be equal to the number of traffic lanes, and the width of the design lanes should be equal to the widthofthe traffic lanes.

Blast Load: Blast loads are considered as most extremes loads and even a small amount of blast can produce a serious damage to the structure.

Table 1: Equivalent Static Parameters for 500 lb of TNT Explosion

R (ft)	V (ft/sec)	TOA (msec)	P (psi)	I (psi-msec)	td (msec)
4	13.13	0.22	2511	9312	0.68
5	13.39	0.3	1884	6336	0.66
6	10.11	0.4	1480	4577	0.66
7	9.13	0.5	1198	3645	0.67
8	8.34	0.61	991	2953	0.68
9	7.69	0.73	832	2462	0.7
10	7.13	0.87	707	2098	0.73
11	6.63	1.01	607	1820	0.76
12	6.2	1.17	524	1602	0.8
13	5.81	1.34	456	1426	0.84
14	5.45	1.52	399	1283	0.89
15	5.14	1.71	351	163	0.95
16	4.85	1.91	310	1063	1.01
17	4.58	2.13	275	977	1.08
18	4.34	2.35	245	903	1.15
19	4.12	2.59	219	839	1.23
20	3.92	2.84	197	783	1.32
21	3.74	3.11	177	733	1.41
22	3.57	3.38	161	689	1.51
23	3.42	3.67	416	650	1.61
24	3.28	3.97	133	615	1.72
25	3.15	4.29	121	583	1.84

The variation of the pressure with respect to distance from the point of explosion is shown in Figure 3. The closer is the explosion to structure; the more severe is the resulting pressure and the likelihood of structural damage. Figures 3 and 4 show elevation and plan views of typical blast pressure distribution on a bridge surface. In order to simplify the method of blast distribution, distribution of blast load was carried out as shown in Figure 3.

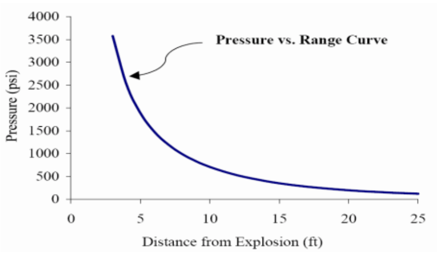

Figure.4 Variation of pressure from distance of explosion

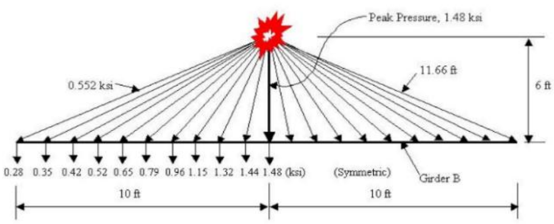

Figure 5 Blast pressure distribution on bridge deck (elevation)

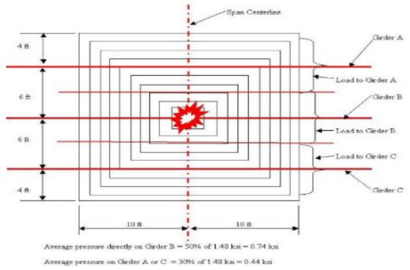

Figure 6. Blast pressure distributions on bridge deck (plan)

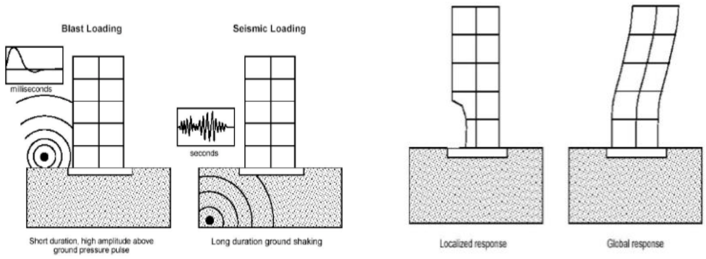

Figure 7. Comparison of blast and seismic actions on structures

Suspension bridge implementation: Description of each of subgroup with total number of elements used along with the total length of the each members and the type of the element used are listed down in Table 2.

Table 2: Description of different sub components of the bridge model

Type of element	Total Length	Number of element	Member type
Towers	1466.32	260	Truss
Cables	6087.62	148	Truss
Hangers	9037.77	142	Truss
Floor Truss	30536.75	2046	Truss
Lateral Bracing	18140.95	868	Truss

The material that was used in construction of the bridge was galvanized wire, wide flanges and other compound steel sections. The material property that was applied to the model bridge for actual represent of the structure is as shown in Table 3.

Table 3: Material property

Material	Steel
Density	0.49 kips per cubic feet
Co-efficient of linear expansion	6.5E-6/°*C*
Young's modulus	4176000 kip/ft^2
Poisson ratio	0.3

The dead load was applied on the entire bridge and the analysis of the bridge was carried out. But for the live load, only the quarter of the bridge was modeled (Figure 4.2) and analysis was carried out.

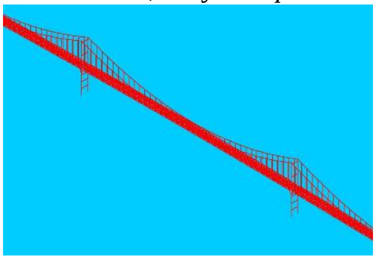

Figure 8. Bridge model in STADD PRO V8i

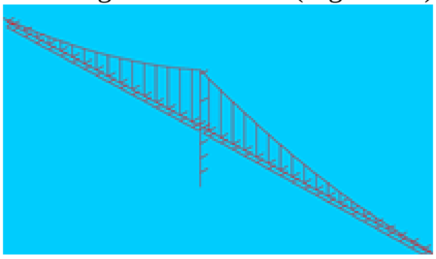

Figure 9. Live load analysis model in STADD PRO V8i *STADD PRO V8i Bridge Model*

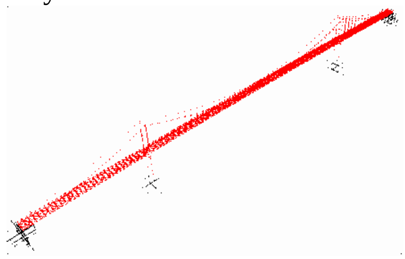

Figure 10.Bridge model in STADD PRO V8i BLASTLOADCASES

Load case	location	Blast set-back
Case 1	Mid-span ofthe center span	6 feet above the deck
Case 2	Mid-span ofthe end span	6 feet above the deck
Case 3	End-span of the centerspan	6 feet above the deck

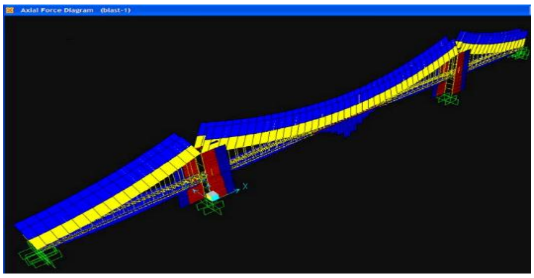

Figure 11 Axial force diagram for blast load case 1

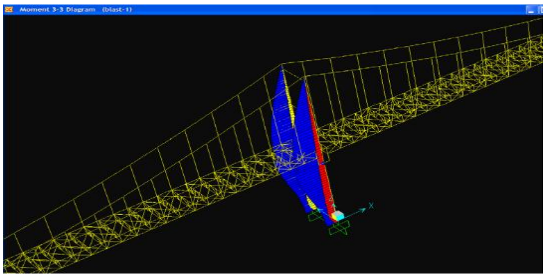

Figure 12. bending moment diagram on tower for blast load case 1

Progressive Collapse: Local failure of a structural element may cause failure of other elements of the same structure.

Table 4: Results for Plastic hinge located at node 942

Step	P	U1Pl	U1PlMax	U1PlMin	U1State	U1Status
	(Kip)	(in)	(in)	(in)		
0	863.006	0	0	0	A ≤B	A≤IO
1	1941.219	0	0	0	A ≤B	A≤IO
2	1979.023	0	0	0	A ≤B	A≤IO
3	-196.29	0	0	0	A≤B	A≤IO
4	-607.672	0	0	0	A ≤B	A≤IO
5	-889.536	0	0	0	A ≤B	A≤IO
6	-946.447	0	0	0	A ≤B	A≤IO
7	-884.985	0	0	0	A ≤B	A≤IO
8	-1575.105	0	0	0	A ≤B	A≤IO
9	-2795.405	-0.007607	0	-0.007607	B ≤ C	A≤IO
10	-3138.39	-0.440825	0	-0.440825	B≤ C	IO ≤ LS
11	-3426.808	-0.805119	0	-0.805119	B≤ C	LS ≤ CP
12	-3443.633	-0.82637	0	-0.82637	B≤C	LS ≤ CP
13	-0.034	-1.174431	0	-1.174431	> E	> CP
14	-0.034	-1.174431	0	-1.174431	> E	> CP
15	-0.034	-1.174431	0	-1.174431	> E	> CP
16	-0.034	-1.174431	0	-1.174431	> E	> CP
17	-0.034	-1.174431	0	-1.174431	> E	> CP

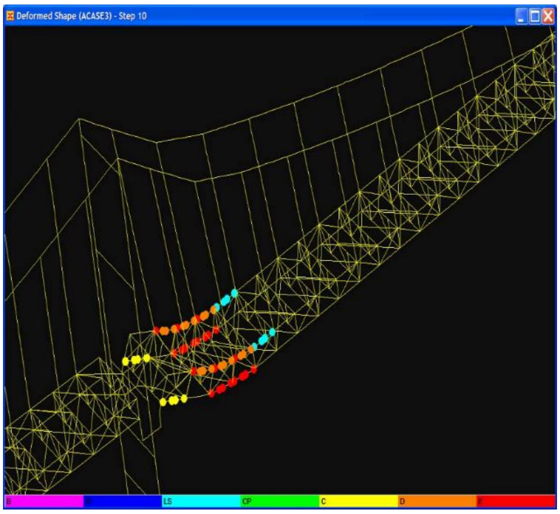

Figure 13. Formation of plastic hinges due to blast load 3 (Step 10)

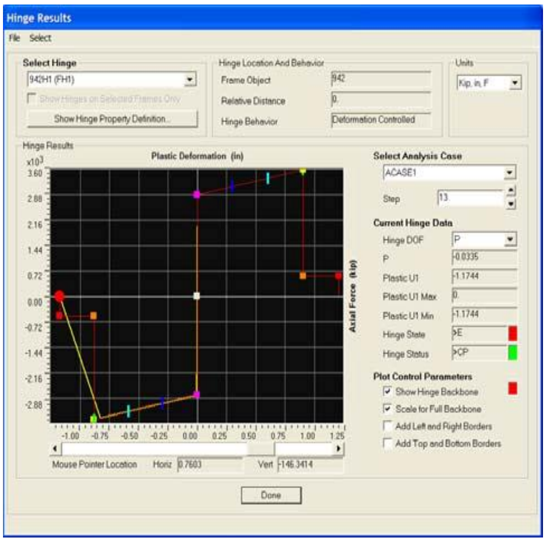

Figure 14. Relation between Plastic deformation Vs Axial force (Step 13)

2. SUMMARY OF RESULTS

Table 5: Effects of the initial stress on the deflection of the bridge

Deflection due to live load with initial stress	Deflection due to live load without initial
78 in	230 in

Table 6: Max vertical displacements due to application of blast loads combination (1.25DL + 0.5LL + 1.0BLAST)

Blast load case	Max vertical displacement
CASE 1	540.27 in
CASE 2	287.69 in
CASE 3	340.21 in

3. CONCLUSION

Firstly, it should be mentioned that the suspension bridge is a "signature" facility and should be designed for security. Operating security measures are in place and employed by bridge owners who operate "signature" facilities. Also site improvement and operation procedures will often prove to be more cost effective than structural engineering solutions. Research is needed to assess structural responses and to validate and calibrate methods and models. Structural engineering guidance needs to be developed by expanding on work by DOD and AASHTO/FHWA Blue Ribbon Panel (BRP) through research leading to design guidance.

This model is a typical suspension bridge with assumptions to make the analysis simpler. 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 members against the blast.

The dead and live load results from finite elements of twareSAP2000 were in close proximity with that of VBDS software, which was used in the cost allocation study. The blast load analysis when carried out in SAP2000 will basically allow the researcher to determine the effect of blast on a suspension bridge under nonlinear analysis.To simulate the blast load, the results were based on the equivalent static load rather than the dynamic loading on the suspension bridge. A numerical model that was created using SAP2000 finite-element-analysis software considering material and geometric nonlinearity. Three blast load cases at the middles of central span and end span and also near the tower were investigated. These three blast load cases that were taken into account reveals the local failure (plastic hinges formation) of the members. The blast load cases that were applied at the center of the spans (blast load case1 and 2) had more severe effect than that of blast that was applied near the tower (blastloadcase3). However, the third blast load case is critical due to its closeness to the tower.

Suspension bridge is a highly redundant structure due to its multi-cell tower sections, multi-strand cables and hangers, and truss sections. It is also concluded from the analytical results that the bridge suffered a local failure, but not a global failure, under the application of blast loads. From progressive collapse results, it can be concluded that parts of the bridge members failed due to application of blast loading, especially those which were directly under the blast load applications. The plastic hinges that were formed on the top and bottom chord of the members just below the blast loads could be considered in a performance state of “collapse prevention”, but the performance level was “life safety” and even “immediate occupancy” for members away from the blast load.This research only demonstrates the vehicular-bound blast load cases on the deck of a suspension bridge. Further research should be done on different blast loads at different locations on a random basis.

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