# Blast Effects on the Structural Response of a Highway Bridge

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**Abstract** This paper aims to present blasting effects on the structural response of a highway bridge considering its piers and decks. In the paper, it describes three-span highway bridge, its analytical modelling, explicit analysis for blasting effects and results obtained from analyses. In the study, 3D finite element model of the highway bridge is constituted using ANSYS Workbench software and blasting analysis are explicitly performed in ANSYS AUTODYN software. TNT is exploded to give blasting effects on the bridge. The duration of the explosion is set to 3 msec. Total strain energy, displacements and stresses due to blasting on the some gauge points are presented. It is seen from the study that the blast causes the local damages on the bridge pier.

## 1 Introduction

In late years, design of new structures have changed due to requirements, such as; high rise buildings, hospitals and schools with big capacities, high bridges and viaducts with large span etc. according to this situation conventional methods are not enough to design them so that most countries produced new standards [1-3] to design the structures.

But nowadays, terrorist attacks are one of the biggest problems in the world. A terrorist attack usually shows itself with an explosion of a bomb which can cause catastrophic effect on buildings, roads, environments and people. An explosion can damage a structure badly; if the charge weight of the bomb is big enough, it can demolish the structure. Blast loads are not calculated and they can be greater than the design load of the structure. Important and critical structures such as hospitals, public buildings, schools, military buildings, bridges and etc. should be designed at project phase in order to resist blast loads. Fujikura and Bruneau [4], studied about blast resistance of seismically designed bridge piers. In the study, the purpose is to search the behavior of seismically designed columns, piers of the bridge. On this experimental research the results test specimens have analyzed and compared with empirical formulas.

Anil and Zhihua [5] studied empirical formulas and computer programs. A highway bridge model has simulated analyzed under blast load and empirical formulas have given to describe the model and blast load. In addition suggestions have given for the model against blast load.

NCRHP [6] offers; descriptions, instructions and design criteria for blast effect. In addition classifies types of explosives and protection criteria. It also gives suggestions on designing the details of bridges.

Also there are some studies related the blasting effects of the bridge in the literature. [7-9].

In this study blast effects on the structural response of a highway bridge is investigated. For the purpose, a three spans highway bridge with 40 m span is selected for the numerical example. In the study, the bridge is exposed to 4 t TNT blasting effects for 3ms. The results obtained from the study are given as contour diagrams. It is seen that the blast causes the local damages on the bridge pier.

## 2 Theory of Blast

The act of explosion can be modeled as a pressure-time graph which can be drawn in Fig. 1. According to the graph in Fig. 1, “0” is the start time of explosion before the shock wave reaches to the structure (t0) in the millisecond range and subjects (pressure reaches to $P_{so}$ immediately) pressure to surface; $P_o$ and duration are related to some important parameters such as charge weight (W), distance (R) from the surface, and type of the material. Generally duration of the explosion is approximately 2,5 ~ 3 milliseconds and value of $P_{so}$ can reach to big overpressures [10-11].

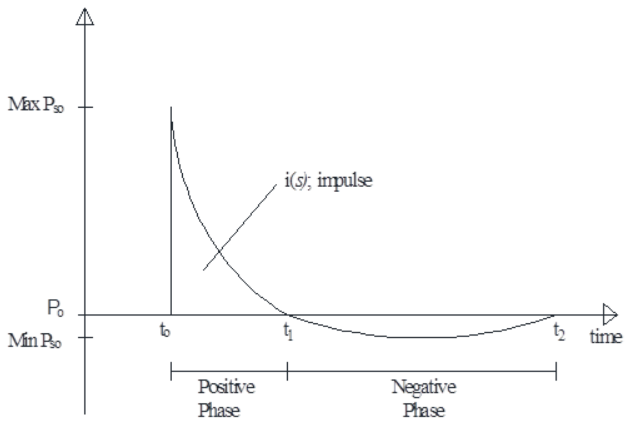


**Fig. 1.** Pressure- Time graph of the explosion [12]

## 3 Numerical Example

In this study, a three-span highway bridge is preferred to simulate a highway bridge which can be seen commonly in Turkey (See Fig. 2). So 3D drawing model of a three-span highway reinforced concrete highway bridge selected for numerical example is given in Fig.3. As seen in Fig. 3 that, main structural elements of the highway bridge are RC columns, beams and span. Also the model contains air and void and TNT. The geometrical dimensions of the bridge are presented in Fig. 4. As seen in Fig. 4 that, the structure has 23 m column height, 40 m span length and has 5x8 m foundation with 2 m height. It has two and one bays along to orthogonal directions. The dimensions are in ‘mm’ types in Fig. 4.

**Fig. 2**. Photos of a highway bridge

### *3.1 3D Model of the Highway Bridge*

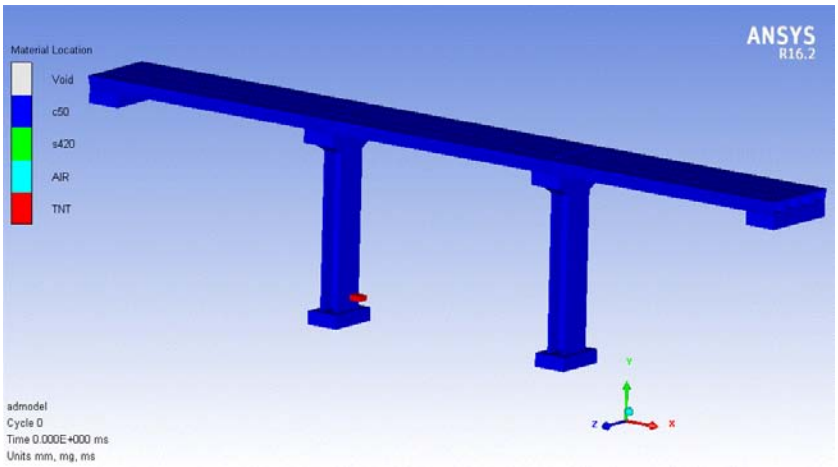


**Fig. 3.** 3D finite element model of the highway bridge

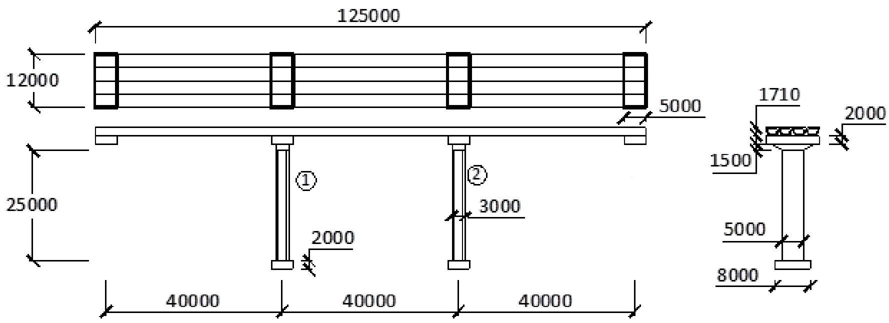


**Fig. 4.** Dimensions of the highway bridge, (units are mm)

The three-span highway bridge subjected to the study have two columns with I cross section and dimensions can be seen in Fig. 4, the length of the beams are 40 m, the height of the reinforced concrete beam is assumed as 171 cm. The dimensions and cross sections (see Fig. 5) and properties given here for RC columns and beams are suitably selected for a highway bridge against to dead, live and earthquake loads according to [13].

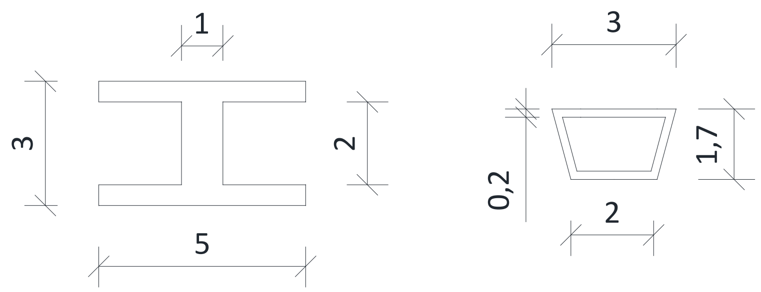


**Fig. 5.** Cross sections and dimensions of the column and beam, (units are m)

According to geometrical properties, 3D finite element model of three-span highway bridge constituted using [14] software as given in Fig. 3 Explosion material is selected as 4 tons of TNT and it is placed next to the bottom of the column. Blast modeling is constituted using [15] software, also the explicit analysis of the highway bridge is performed in this software for a duration of 3 micro seconds. The material properties of components used in the modeling and analysis such concrete, reinforcement, air, and TNT are given in Table 1.

**Table 1.** The material properties of components used in the modeling

| Material Component | Material Type | Elasticity Modulus (MPa) | Density ($g/cm^3$) | Compressive Strength (MPa) | Tensile Strength (MPa) |
|---|---|---|---|---|---|
| Concrete | C50 | $3.7 \times 10^4$ | 2.75 | 50 | 5 |
| Reinforcement | S420 | $2 \times 10^5$ | 7.83 | 420 | 420 |
| Air | Air | - | $1.23 \times 10^{-3}$ | - | - |
| Blasting | TNT | - | 1.63 | - | - |

### *3.2 Gauge Points*

Before blast analysis, some gauges have plotted on the members of the highway bridge. 9 gauges have plotted on some points in order to analyse some values after blast (see Fig. 6)

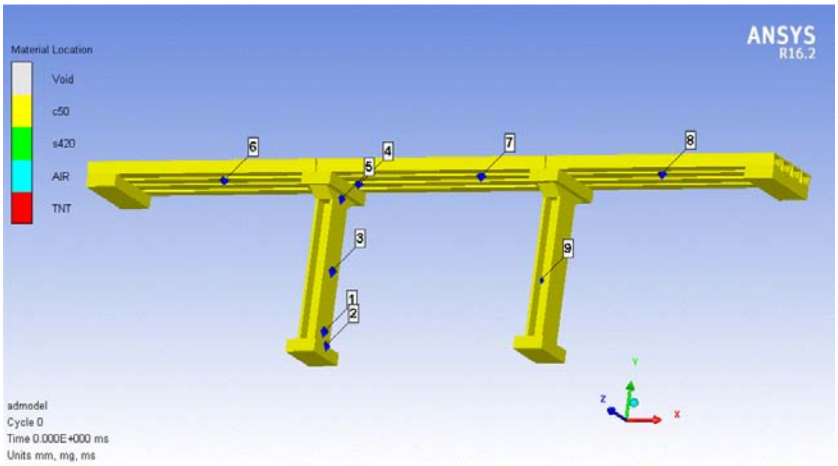


**Fig. 6.** Plotted gauge points on the 3D finite model

## 4 Analysis and Results

After performing explicit analysis considering explosion, the deformed shape of the three-span highway bridge is illustrated in Fig. 7 in which, column number 1 and foundation is damaged partly, especially concrete at bottom p damaged and fragmented. On the other hand other members have not damaged. Elastic, plastic and failed areas of the can be noticed on Fig. 7.

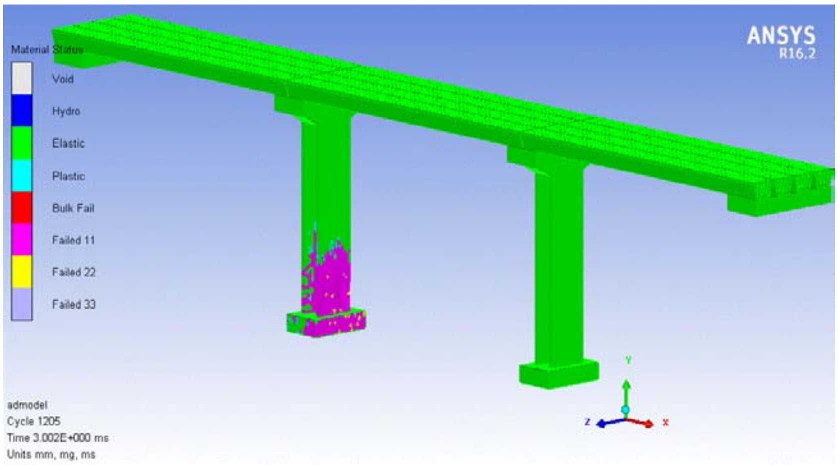


**Fig. 7.** Situation of the members after explosion

The pressure values on the elements of the highway bridge obtained from blasting analysis are demonstrated in Fig. 8. It can be seen from Fig. 8 that, biggest values are occurred on the column number 1 with max pressure (absolute) value of 382 mPa at X direction approximately. This means; value of overpressure at X direction means shear force and can be very dangerous for the column.

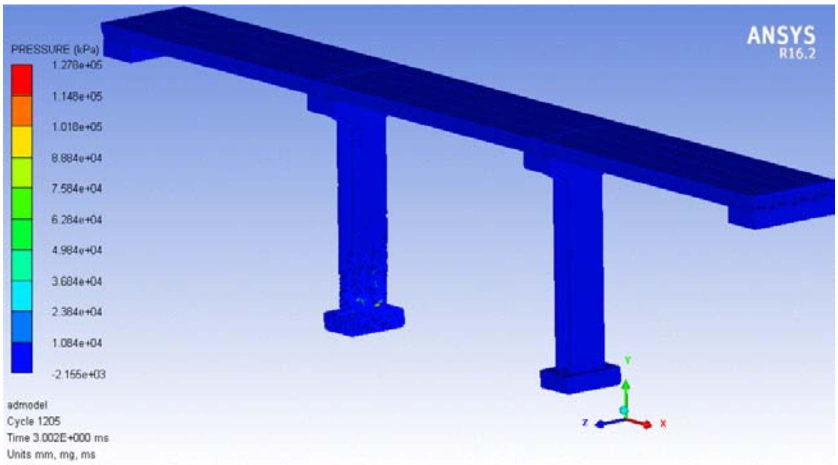


**Fig. 8.** Pressure values of the highway bridge obtained from blasting analyses

The time histories of the pressures on the gauge points are plotted in Fig. 9.The maximum values of the pressure on the gauge points are listed in Table 2. Blast effect subjected biggest values of pressure on Gauge 1 and gauge 2 respectively, especially pressure on gauge number #1 rises suddenly and big overpressures are very dangerous for the concrete member. On the other hand damage values of other gauges are too small that can be neglected.

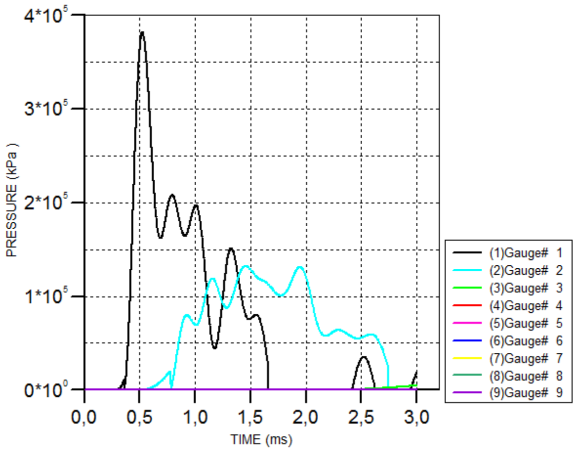


**Fig. 9.** The time histories of the pressures on the gauge point

**Table 2.** Pressure values taken from gauges

| Gauge Number | Pressure Value (MPa) |
| --- | --- |
| #1 | 381,92 |
| #2 | 132,11 |
| #3 | 2,02 |
| #4 | 0,12 |
| #5 | 0,11 |
| #6 | 0, 00 |
| #7 | 0, 00 |
| #8 | 0, 00 |
| #9 | 0,13 |

Values of damages (see Fig. 10) can be noticed from damage-time graph and according to the graph gauge number #1 and number #2 takes %100 percentage of damage. Gauge number #1 reaches to %100 damage in 1,6 ms and gauge number #1 reaches to %100 damage in 2,7 ms. On the other hand damage values of other gauges are too small that can be neglected.

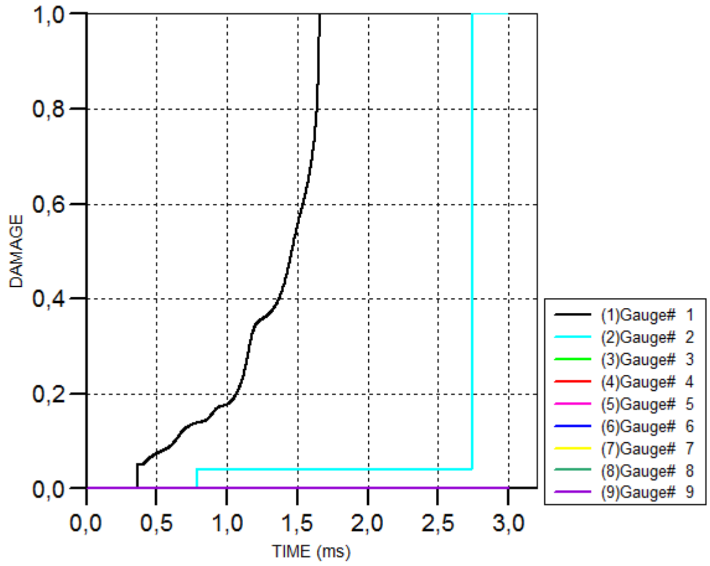


**Fig. 10.** The time histories of the damage on the gauge point

The time histories of the displacements on the gauge points are plotted in Fig. 11. As seen in Fig. 11. maximum displacements are occurred on the gouge points #1 and #2, respectively. also, the maximum values of the displacements are listed in Table 3. Gauge number #1 shows the biggest value of displacement with 14,5 cm approximately and gauge number #2 shows displacement with 11 cm approximately. On the other hand displacement values of other gauges are too small that can be neglected.

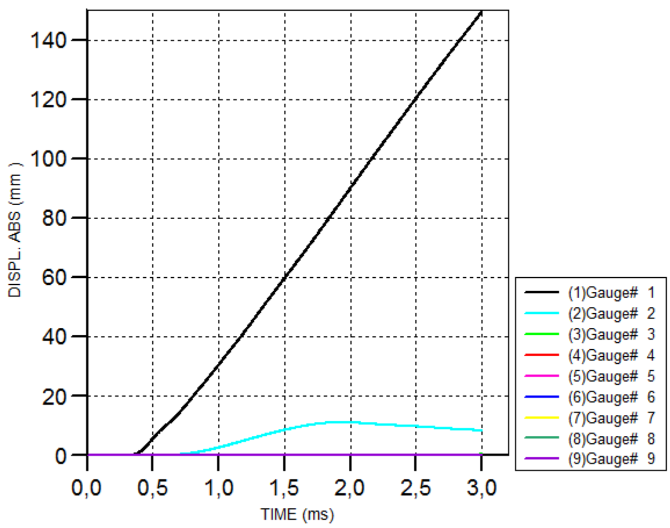


**Fig. 11.** The time histories of the displacements on the gauge point

**Table 3.** Displacement values of gauges

| Gauge Number | Displacement (mm) |
|---|---|
| #1 | 145,00 |
| #2 | 11,00 |
| #3 | 0,07 |
| #4 | 0,05 |
| #5 | 0,04 |
| #6 | 0,03 |
| #7 | 0,03 |
| #8 | 0,03 |
| #9 | 0,03 |

During explosion, explosive material TNT releases big amount of energy and the members of a structure (including air) absorb some of the energy released. (see Fig. 12). According to the graph and table, the energy which released by TNT, is totally absorbed by members. (most of the energy absorbed by air). In the study, released and absorbed energy values obtained from the analysis can be seen (see Table 4)

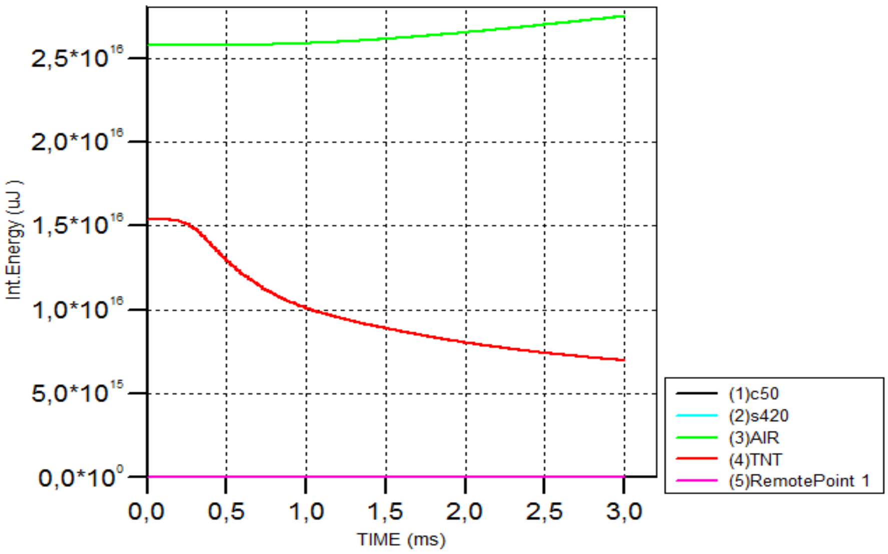


**Fig. 12.** The time histories of the total energy on the gauge point

**Table 4.** Released and absorbed energy values

| Member | Energy (uJ) |
|---|---|
| C50 Concrete | $8{,}9363.\ 10^{13}$ |
| S420 Reinforcement | $4{,}3817.\ 10^{12}$ |
| Air | $2.8516.\ 10^{16}$ |
| TNT | $1.5360.10^{16}$ |

## 5 Conclusions

In this study, structural response of a three-span highway reinforced concrete bridge under blasting effects is investigated. A three-span highway bridge is selected for the numerical example. The 3D finite element modeling of the bridge is constituted in ANSYS Workbench software. The blasting load is assumed for four tons TNT next to bridge column bottom and explicit analysis for 3 micro seconds is performed using ANSYS Autodyn software. The blasting effects on the structural and nonstructural elements of the bridge according to analysis results are presented. Also the fallowing conclusions and discussion are made from the study:

- ✓ Only column number #1 and foundation has damaged highly and concrete at bottom place collapsed.
- ✓ The other members have not taken any damage from explosion.
- ✓ Nearly 41,6 MPa pressure is occurred on column and foundation of the bridge due to blasting, and this causes the highly damage ratio on the structural element of the bridge. On the other hand the damage ratios are negligible on other members.
- ✓ Big charge mass of explosives can demolish structures completely. So it is recommended that the structures (especially vital structures) have to be designed at project phase against explosive loads. Step by step, designs have to be made through handbooks, standards and instructions to blast loads.

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## References


1. TSC, (2007). Turkish Seismic Code. Chamber of Civil Engineering, Ankara
2. Earthquake Standard of High-rise Buildings in Istanbul, (2008), Istanbul Metropolitan Municipality.
3. Wind Standard of High-rise Buildings in Istanbul, (2009), Istanbul Metropolitan Municipality.
4. Fujikura S., Bruneau M. "Blast Resistance of Seismically Designed Bridge Piers" The 14th World Conference on Earthquake Engineering, October 12-17, Beijing, China
5. Anil K., Zhihua Y. (2009) "Blast Load Effects on Highway Bridges" Region 2 University Transportation Research Center.
6. National Cooperative Highway Research Program, (2010) Transportation Research Board. "Report 645".
7. Rong-Bing Deng, Xian-Long Jin. (2009) Numerical Simulation of Bridge Damage under Blast Loads. Wseas Transactions On Computers.8(9), ISSN: 1109-2750
8. Sam A. Kiger, Hani A. Salim, and Ahmed Ibrahim. (2010) Bridge Vulnerability Assessment and Mitigation against Explosions, Iowa State University, Final Report.
9. William F. C., Debra S. Matthews and David I. McLean. (2012). Effects of Blast Loading On Prestressed Girder Bridges. Shock and Vibration 19, 1-18.
10. TM 5-1300. (1990). Structures to Resist the Effects of Accidental Explosions, U.S. Departments of the Army, Navy, and Air Force, USA,
11. TM 5-855-1. (1986) Fundamentals of Protective Design for Conventional Weapons, U.S. Department of the Army, USA,
12. Mills, C.A. (1987) .The Design of Concrete Structure to Resist Explosions And Weapon Effects, Proceedings Of The 1st Int. Conference on Concrete For Hazard Protections, Edinburgh, UK, pp. 61-73
13. Turkish Standard 500 (2000), Requirements For Design And Construction of Reinforced Concrete Structures, Institute of Turkish Standards, Ankara
14. ANSYS, Workbench (2016), Ansys Inc. USA.
15. ANSYS, AUTODYN (2016), Ansys Inc. USA.