Deformations of Bridge Pier Subjected to Blast Loading

V. B. Dawari, P. S. Karmare, B. M. Dawari

Abstract— The events of numerous blast incidences illustrated the catastrophic damage that terrorists can inflict on civil structures. Before and after 2001, major events had followed worldwide of bombing to take down human life’s, overall economy and structures although there were many other events which describes that intentional/unintentional explosion doesn’t matter. The effects of these explosions over transportation systems are very vast. This paper demonstrates main damage mechanisms of bridges pier subjected to blast loading. In the numerical study, 90 models of bridge piers with different blast source are analysed using LS-DYNA software for 100 kg equivalent TNT blast weight by varying the distance of blast from the bridge pier. Analysed bridge piers are designed for the blast loads. The paper also compares effect of blast load on gravity loaded pier. It is observed that bridge pier designed for blast resistant have greater capacity to resist the blast load than the bridge pier designed for superstructure loads for almost every explosion source location.

Index Terms— blast, bridge pier, analysis, design, LS-DYNA, TNT

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1 INTRODUCTION

THE events of September 11, 2001, illustrated the catastrophic damage that terrorists can inflict on structures, the terrorist attack always targets on human casualties and economic consequences which leads to an unforgettable loss to a nation as well as to the nearest society. The number and intensity of domestic and international terrorist events, including the September 11, 2001, attack have heightened the concerns toward the safety of infrastructure systems. Before and after 2001, major events had followed worldwide of terrorist attack to take down the structure, to cause human casualties to threaten the economy.

The nearest threat occurred was on February 13, 2010 in Pune, Maharashtra, India, where the blast happened in a bakery and 17 people got killed and more than 60 people were injured. In a bomb blast in April 19, 1995, the Alfred P. Murrah building which was a United States federal government complex in Oklahoma City was attacked [1]. As a result of a large truck bomb (of approx. 3200 kg), 169 people were killed and over 500 were injured, the damages exceeded $ 652 million overall. Hence it becomes necessary to study the effects of a surface blast on buildings of different heights. Tolani *et al.* [2] investigated effect of air pressure and ground acceleration on multi-storey building considering surface blast. For this purpose, both linear and non-linear analyses of SDOF models of four reinforced concrete building frames of different heights are performed under different blast scenarios [2], [3]. It is found that low-rise buildings, responses are governed by the air pressure effect, whereas for taller buildings, they are governed by the ground shock effect. Magnusson J., and Hallgren M. [4] studied the structural behavior of reinforced HSC beams subjected to air blast loading. The work was focused on study of load and deflection capacity of the beams due to air blast loads. Damage to the assets, loss of life and social panic are factors that have to be minimized if the threat of terrorist action cannot be stopped. Designing the structures to be fully blast resistant is not an economical option for every owner, however current engineering and architectural knowledge can enhance the new and existing buildings to diminish the effects of an explosion. Zeynep *et al.* [5] provided guidance to engineers and architects where there is a necessity of protection against the explosions caused by detonation of high explosives. The blast loading parameters and enhancements for blast resistant building design both with an architectural and structural approach is given in this literature.

Loads imposed on highway bridge components during a blast loading event can exceed the design capacity of those members. In some cases, the loads can be in the direction opposite to those of conventional design loads. Consequently, highway bridges designed using current design codes may suffer severe damages even from a relatively small size explosion. There is very limited information available on analysis, design, and detailing of bridge components subject to blast loads. The most detailed literature available in this area is the National Cooperative Highway Research Program (NCHRP) 645 report titled “Blast-Resistant Highway Bridges: Design and Detailing Guidelines” [1] which presents some simplified design guidelines against blast loads. However, this guideline also does not provide much information on failure modes of different bridge components during blast loads. The majority of the current state of knowledge for the design of structures subjected to blast loads is based on and directed toward the performance of military structures and civilian buildings. There has been very little notable research on the blast-resistant design of highway bridges.

The bridges are very complex systems. Decision making on blast threats (charge type, size, and location), identification of bridge components affected by the direct blasts, and severances of existing bridges can be scary, even for the simplest of bridges. The Blue Ribbon Panel placed gives some priorities for the bridges trying to protect the bridge first priority on deterrence, denial, and detection of blasts, second priority on defense with standoff, and third priority on structural modifications through design and detailing [6]. The Blue Ribbon Panel has recommended minimum barrier standoffs for different vehicular threat types in terms of explosive weight (kg of TNT). However, it may not be possible to provide adequate standoff to protect existing bridge piers on busy highways due to traffic requirements. In such cases, strengthening of bridge components becomes the only viable protective option. The special literatures are studied for the understanding of the blast loads over the structure, its response and understanding the software LSDYNA [7], [8],[9].

The studies of blast loading showed that blast loads are impact loads which travel through different mediums to cause severe damage to the localised area. The pressure created by the explosion carries a high intensity in small time period [10]; the Pressure-Time history of blast load is shown in the Fig.1.

In the present study, Air burst and Surface burst are taken into account to determine the dynamic blast loads on the surface of the hammer head bridge pier. The bridge pier is first analysed for the blast pressure of 100 kg TNT equivalent blast at 90 different locations over commercial available software - LS-DYNA. The location of the blast sources are kept at 90 different locations starting from 1 m to 10 m horizontally from pier surface. On each of the horizontal distance, blast source is kept from ground surface i.e. 0 m to 8 m vertically at increment of 1 m interval. Next, the bridge pier is designed as per guidelines in NCHRP report 645 and similar analysis is repeated for the bridge pier designed for blast loads on same 90 locations as mentioned earlier. The paper also presents observation about the how the superstructure loads gives minor additional resistant to the bridge pier when subjected to blast load.

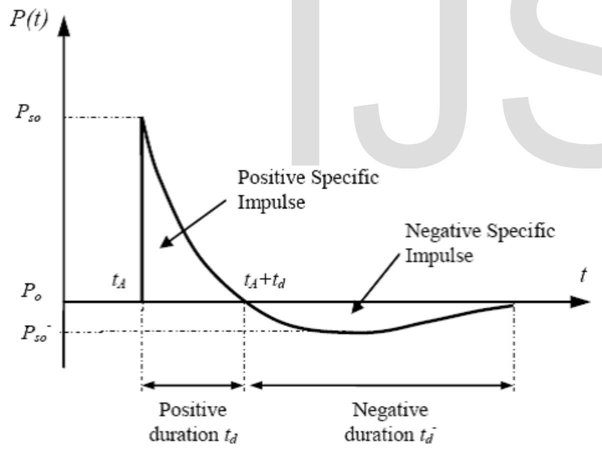

Fig. 1. Magnetization Idealized pressure–time curve for free-air explosion

2 NUMERICAL STUDY

2.1 Target Bridge Pier

The bridge pier considered is a hammerhead bridge pier of Flyover Bridge, taken under consideration that it is situated at city area. The bridge analysis is done at various 90 locations over commercial available software - LS-DYNA, for explosion weight of 100kg. Williamson *et al.* [11] proposed three design categories A, B, and C for blast resistance. These design categories depend on a formula of scaled standoff parameter $Z = R / W^{1/3}$ where, R is actual standoff distance and W is weight of design explosive charge. As per Williamson *et al.* [11] for different category, special blast resistant guidelines were given. Design category A does not require any additional blast resistant improvements; Design category B require the transverse reinforcement should be provided throughout the pier height with improvements; Design category C should satisfy all requirements from design category B and the total cross-sectional area of transverse reinforcement should have 50% increment. The literature also recommends changing the geometry of bridge pier cross section to circular.

2.2 Bridge pier models in LSDYNA

The target bridge pier is considered for the blast load analysis have height of 8.49m and it is square in cross section, as shown in Fig. 2. The bridge pier designed as per NCHRP report [1] is as shown in the Fig. 3. The modeling and meshing of the bridge pier is done in LSDYNA LS-PREPOST 4.5. The meshing of concrete is done using solid 8 nodded irregular Hexahedral and 6 nodded Pentahedral elements and steel reinforcement rebar's is done using beam elements.

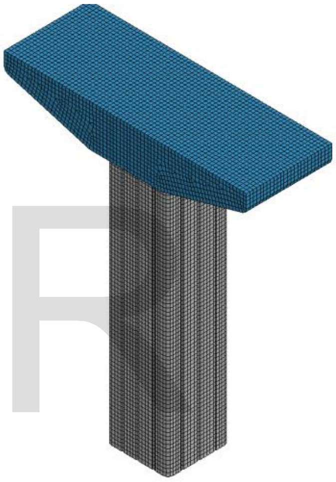

Fig. 2. Target bridge pier

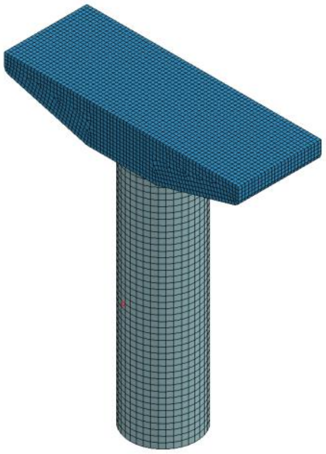

Fig. 3. Blast Resistant designed bridge pier

2.3 Material Modeling

The material card 159 MAT_CSCM_CONCRETE is available for solid elements in LSDYNA. As its property is the automatic generation of model parameters based on few inputs, it is easier to carryout analyses of the structure with this material card. In this study, analysis of bridge pier is done using 159 MAT_CSCM_CONCRETE materials. Continuous Surface Cap Model (CSCM) was developed in 1990s, and was sponsored by the department of transportation (DOT) in the United States of America to be available in LSDYNA in 2005 aimed for road side safety analysis. The material card used for Steel reinforcement bar is material no. 24 MAT_PIECEWISE_LINEAR_ PLASTICITY, this material model represents steel reinforcement behaviour.

2.4 Blast Loading

The blast loading in LSDYNA was applied by the keyword "Load-Enhanced Blast" in this study. The blast load calculations [7] as per IS 4991-1968 are not required here; LSDYNA R11.0 software directly applies the blast pressure on the structure surface from the time histories of blast pressure. The pressure time histories are based on the Conventional Weapon Effects (CONWEP) reflected pressures on a rigid surface. The present study do not consider the reflection and superposition of a blast wave close to the structure components. The analysis is done for 30ms time for 90 different locations and after Time vs. Displacement graphs were plotted to observe the response of the structure to the blast load.

2.5 Validation using LSDYNA software

Validation is done by comparing the analysis result data which is obtained by the LS-DYNA software, with the experimental result data [4]. J. Magnusson and M. Hallgren conducted experiment consists testing of 49 RCC column and beams for blast load and static load. The verification is done by comparison of maximum displacement occurred by blast load on a beam in experimental tests data and software analysis data. The maximum displacement in experiment is 17.5mm and maximum displacement after analysis of beam over LSDYNA is 17.33mm. Displacement in LS-DYNA software and displacement occurred in experiment contains difference of 0.17 mm. 0.97% error between software displacement and experiment displacement is occurred, hence it is verified that method used for applying blast load in software is correct. The verification model was analysed for 30 milliseconds (ms). Fig. 4 shows the blast simulation of beam at 14 milliseconds (ms) and Fig. 5 shows the Time vs. Displacement graph of the beam.

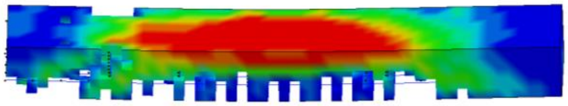

Fig. 4.Validation problem at 14 ms in LS-DYNA

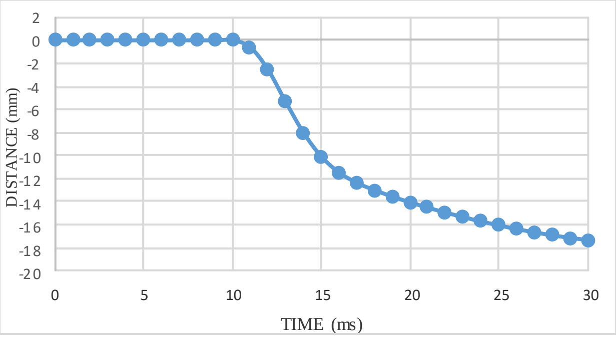

Fig. 5. Displacement vs Time of validation problem

3 RESULTS AND DISCUSSIONS

Blast load analysis over bridge pier is carried out for 90 different locations to understand the response of bridge pier, weight of explosion considered for this analysis is 100 kg TNT equivalent. For every explosion location Time vs Displacement graphs are plotted to understand the global displacements of the bridge pier due to blast. The Fig. 6 to Fig. 15 indicate the Time vs Displacement graphs of bridge pier subjected to blast load which were previously designed only for superstructure load.

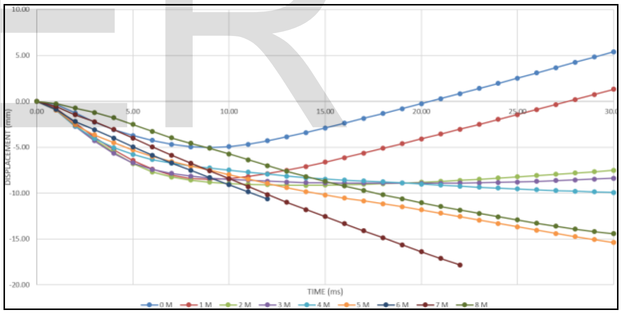

Fig. 6. Displacement vs Time graph of pier for all blast sources at 1m horizontal

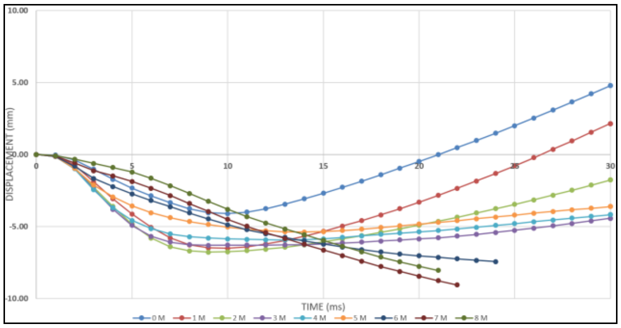

Fig. 7. Displacement vs Time graph of pier for all blast sources at 2m horizontal

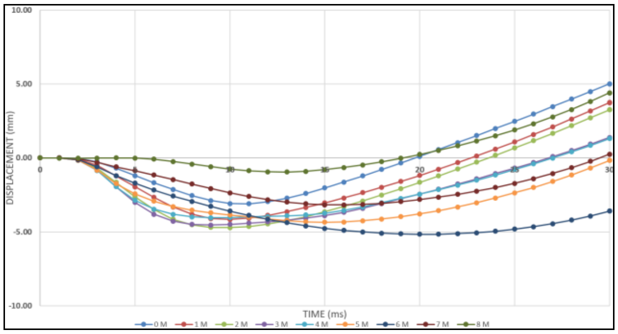

Fig. 8. Displacement vs Time graph of pier for all blast sources at 3m horizontal

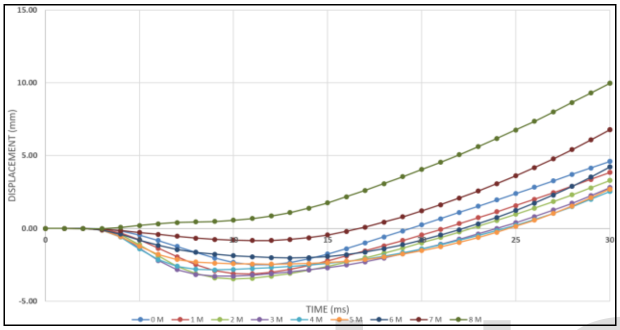

Fig. 9. Displacement vs Time graph of pier for all blast sources at 4m horizontal

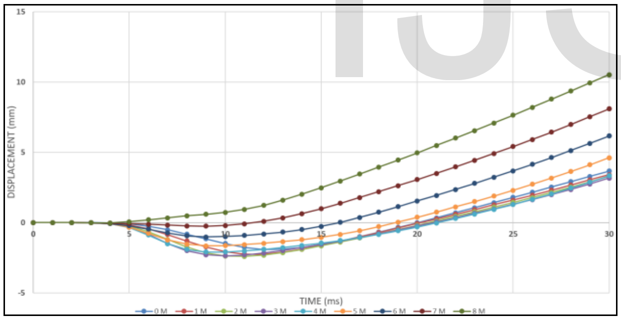

Fig. 10. Displacement vs Time graph of pier for all blast sources at 5 m horizontal

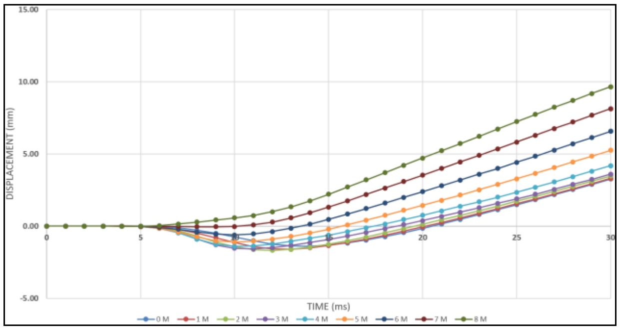

Fig. 11. Displacement vs Time graph of pier for all blast sources at 6 m horizontal

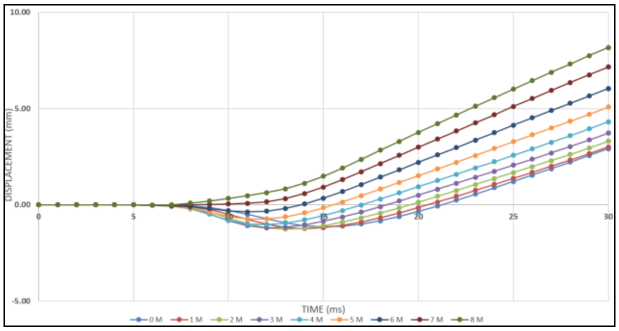

Fig. 12. Displacement vs Time graph of pier for all blast sources at 7 m horizontal

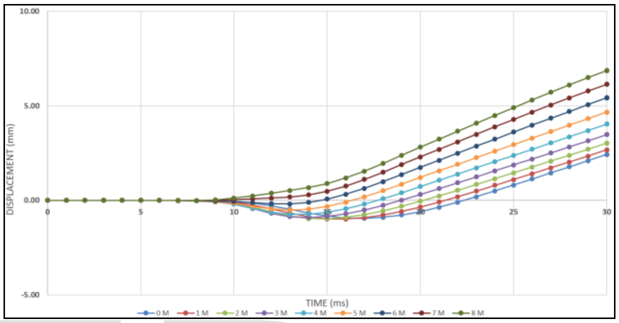

Fig. 13. Displacement vs Time graph of pier for all blast sources at 8 m horizontal

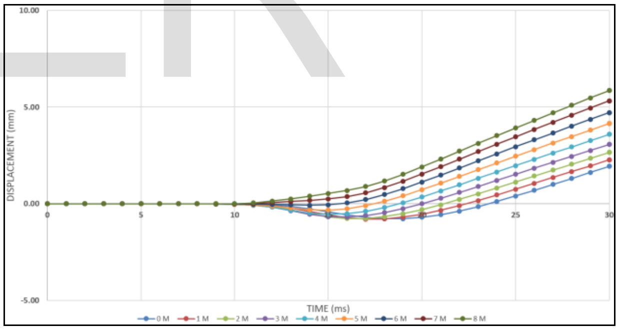

Fig. 14. Displacement vs Time graph of pier for all blast sources at 9 m horizontal

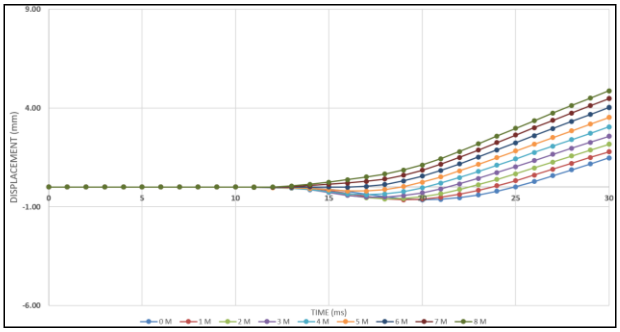

Fig. 15. Displacement vs Time graph of pier for all blast sources at10 m horizontal

After analyzing the bridge pier, the bridge pier is designed considering blast loads and then again analysis of blast load is carried out over the blast resistant designed bridge pier for same 90 locations as earlier. Global displacements graphs were plotted to understand and compare the deflections of both superstructure load designed bridge pier and blast resistant designed bridge pier.

The Fig. 16 to Fig. 25 represents the Time vs Displacement graphs of bridge pier subjected to blast load which designed for 100 kg TNT equivalent explosion charge.

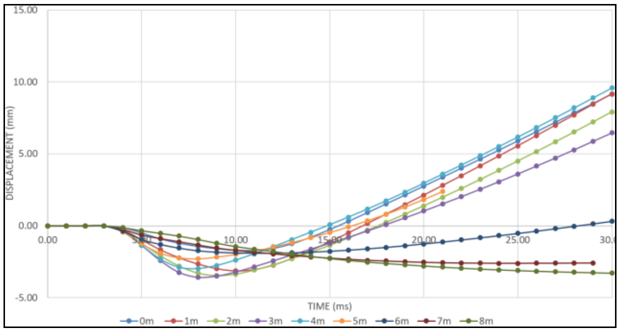

Fig. 16. Displacement vs Time graph of blast resistant designed pier for all blast sources at 1m horizontal

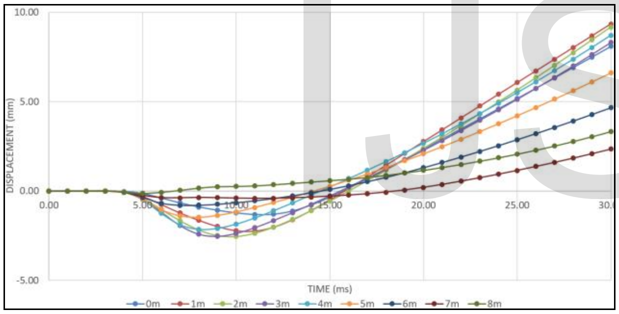

Fig. 17. Displacement vs Time graph of blast resistant designed pier for all blast sources at 2 m horizontal

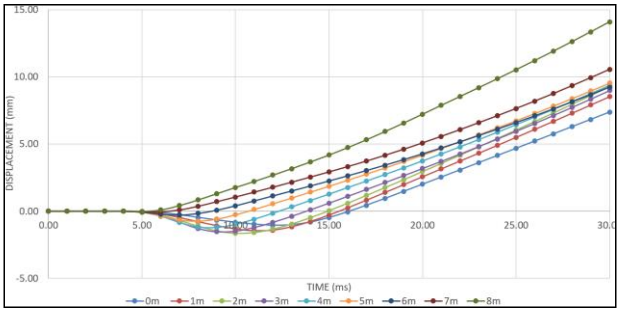

Fig. 18. Displacement vs Time graph of blast resistant designed pier for all blast sources at 3 m horizontal

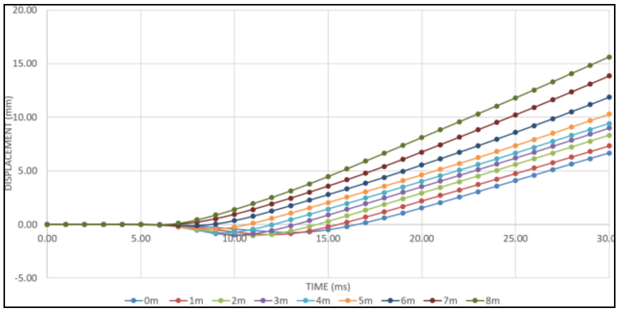

Fig. 19. Displacement vs Time graph of blast resistant designed pier for all blast sources at 4 m horizontal

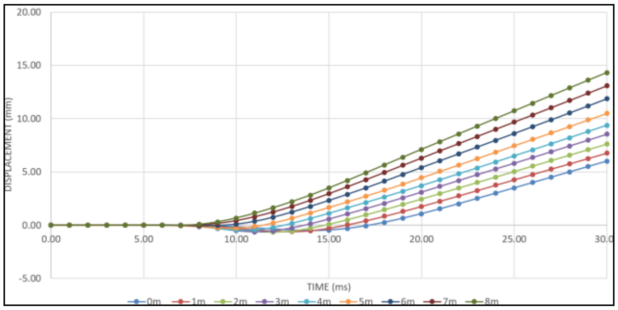

Fig. 20. Displacement vs Time graph of blast resistant designed pier for all blast sources at 5 m horizontal

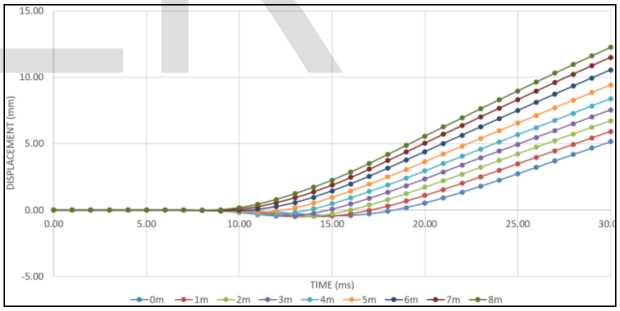

Fig. 21. Displacement vs Time graph of blast resistant designed pier for all blast sources at 6 m horizontal

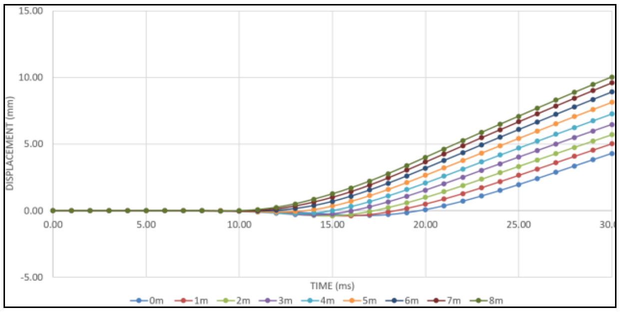

Fig. 22. Displacement vs Time graph of blast resistant designed pier for all blast sources at 7 m horizontal

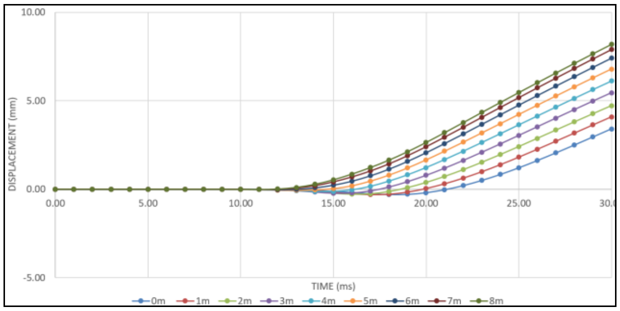

Fig. 23. Displacement vs Time graph of blast resistant designed pier for all blast sources at 8 m horizontal

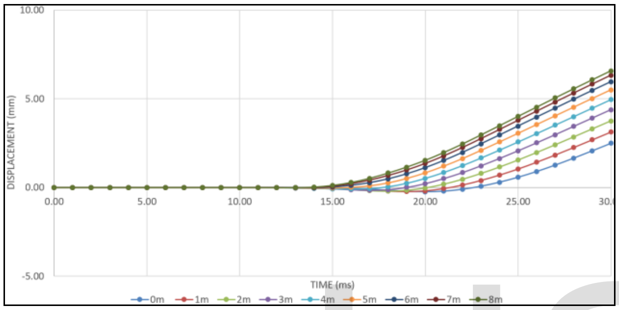

Fig. 24. Displacement vs Time graph of blast resistant designed pier for all blast sources at 9 m horizontal

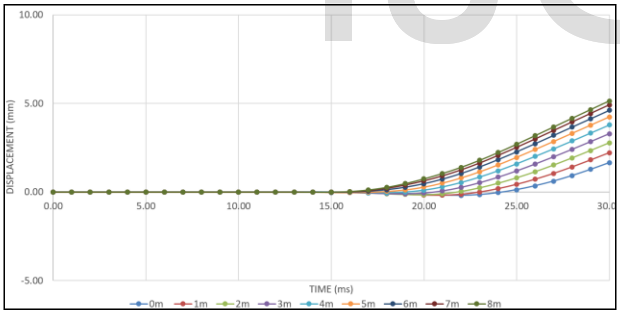

Fig. 25. Displacement vs Time graph of blast resistant designed pier for all blast sources at 10 m horizontal

The blast resistant bridge pier design and blast load analysis of the bridge pier is done without the superstructure loads [1] as directed by specialised literature for bridge pier. To compare the effect of blast load on bridge pier two cases were studied I) Effect of blast load on bridge pier when superstructure loads are considered, II) Effect of blast load on bridge pier when superstructure loads are not considered. The bridge pier is analysed for 100 kg explosive charge weight with above mentioned two conditions. The comparisons of simulated bridge pier with and without superstructure loads in software LSDYNA are shown in the Fig. 26 and Fig. 27, where comparison of displacement vs time graphs of both conditions are shown in the Fig. 28.

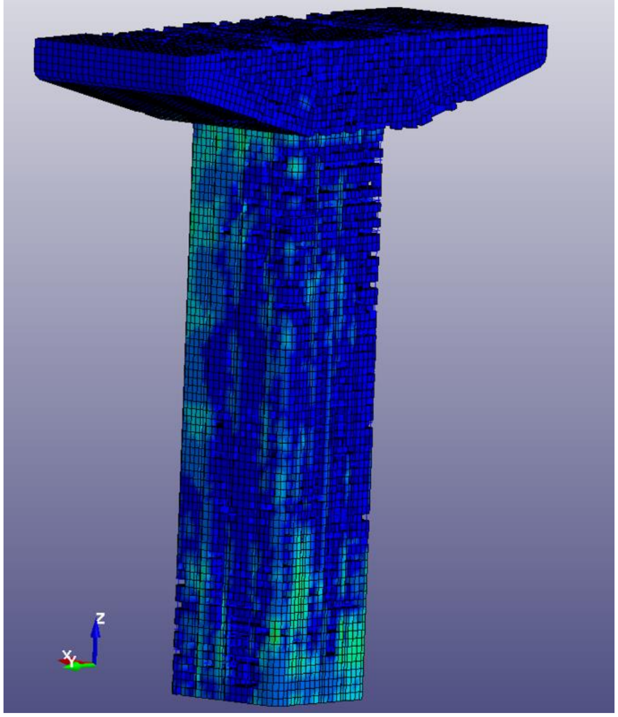

Fig. 26. Simulated bridge pier in LSDYNA subjected to 100 kg blast load considering superstructure load

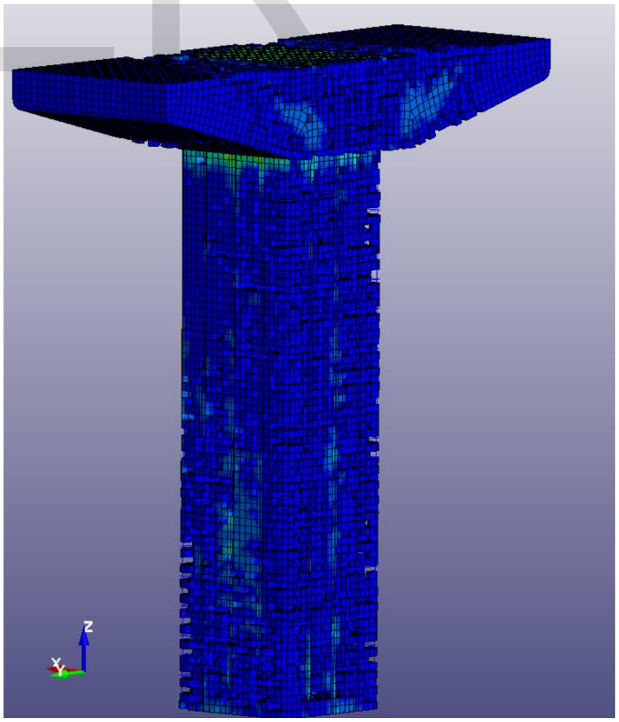

Fig. 27. Simulated bridge pier in LSDYNA subjected to 100 kg blast load without considering superstructure load

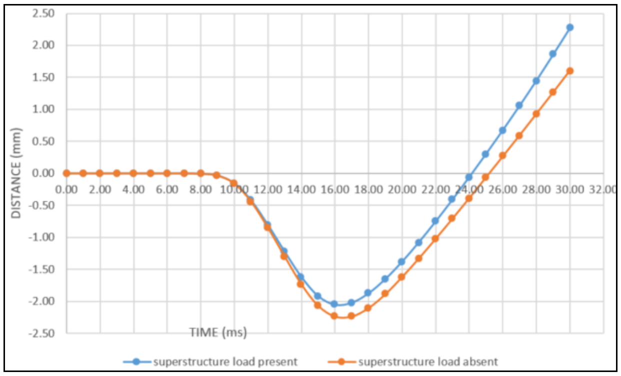

Fig. 28. Effect of Superstructure load on pier deflections

Following observations are noted:

When blast source is on the ground, the blast waves that travels in air towards the structure are less effective than the locations of the blast source in air, because of this the deflections that occur due to blast source on ground is less than the blast source in air. As blast source gets away from the structure the blast wave gets the more surface on which they can incident. When a charge is detonated away from structure, it produces a lower-intensity, longer-duration uniform pressure distribution over the entire structure. As well as when a charge is detonated extremely close to a structure, it imposes a highly impulsive, high-intensity pressure load in a limited small region of the structure. The deflections occurred for the blast load analysis over the blast resisted designed bridge pier are less than the blast load analysis over the bridge pier designed for superstructure loads.

The comparison of simulations of bridge pier subjected to blast load in LS-DYNA software shows that the cracks formed in the bridge pier when the superstructure load is present are comparative less than the cracks formed in the bridge pier where superstructure load is absent. The deflection comparison graph also suggest that the bridge pier have a reduction in the displacement when superstructure loads are present than the deflection in bridge pier without superstructure loads. The reduction in the deflection of the bridge pier is around 8 percent.

4 CONCLUSIONS

The study is carried out for the responses observed for 90 different locations over blast resistant designed bridge pier and pier designed for superstructure loads. It is concluded that, the bridge pier which is designed for blast resistant design has more capacity to resist the blast load then the bridge pier which is designed for the superstructure loads. Superstructure loads also play a blast resistant role in the response of bridge pier when subjected to blast loads

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