Numerical Investigation of RC Beam Subjected to External Explosion

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Abstract - *The world population is increasing at an exponential rate causing increased need for infrastructure all over the world. Large numbers of bridges, metros, viaducts, flyover, skyscrapers etc. are emerging at various locations around the globe every day using various building materials. It becomes imperative to protect these structures from failure due to unprecedented events. The terrorist activities and threats have become a growing problem all over the world and protection of the citizens against terrorist acts are essential. Reinforced Concrete (RC) structures exposed to fire and blast due to accidents or terrorist attacks during their service life. Beam is one of the integral elements in a building framework. The loads due to blasts and/or fire that could act on beams may damage it partially or can cause complete failure. The intensity of the damage depends on the type of explosion and the proximity of the explosion. The aim of this paper is to study the effects of blast loading on an RC beam using FEA model. The software adapted for this work was AUTODYN software and dynamic response of the RC beam exposed to blast is simulated. This study also addresses the mitigation measures to reduce the blast effect on RC beam by adopting similar concepts that are used in sound wave mitigation. Suggest methods to reduce the deflection in beam due to blast. Facet beams show a better reduction in deflection.*

Key Words: **Blast, RC beam, FE model, AUTODYN, facet panel**

1. INTRODUCTION

The terrorist activities and threats have become a major growing problem all over the world and protection of the citizens against terrorist acts involve prediction, prevention, and relief of such events. In the case of structures, structural resistance and physical integrity are different methods to resist the effect. If the structures are properly designed for these abnormal large loads, the damage can be reduced to a particular limit. Additionally, in order to check the safety of existing structures against such events, an evaluation process for their timely inspection and eventual retrofit is needed.

In the past few decades, considerable emphasis has been given to problems of the blast and earthquake. The earthquake problem is old, but most of the knowledge on this subject has been researched during the past fifty years. The explosion issues are new problems; publication of the Army Corps of Engineers gives information about the development is filed, Department of Defense, U.S. Air Force and other government officials and public institutes. Most of the work is done by the Massachusetts Institute of Technology, The University of Illinois, and other top leading educational institutions and engineering firms.

An explosion can be explained it is a large-scale, rapid and sudden release of energy. Explosions can be classified on the basis of their nature as physical, nuclear or chemical events. In physical explosions, a large amount of energy may be released from the catastrophic failure of a cylinder which is filled with compressed gas, volcanic eruptions or even mixing of two liquids which having two different temperatures. In a nuclear explosion, energy is released as a result of the formation of different atomic nuclei by the rearrangement of the protons and neutrons within the interacting nuclei, whereas in the case of chemical explosions the main source of energy is rapid oxidation of fuel elements such as carbon and hydrogen atoms. Explosive materials can be differentiated according to their physical state as solids, liquids or gases. Solid explosives are mainly high explosives for which effects of the blast are best known. The classification is based on the basis of their sensitivity to ignition as secondary or primary explosive. The latter is one of the best things that can be easily detonated by simple ignition from a spark, flame or impact. Mercury fulminates and lead aside such materials are primary explosives. Secondary explosives when detonated create blast (shock) waves which can result in widespread damage to the surroundings. Trinitrotoluene (TNT) and Ammonium Nitrate and Fuel Oil (ANFO) are some of the examples.

The main target of this study is to provide guidance to engineers where there is a necessity of protection against the explosions caused by the detonation of high explosives. This study also gives a brief description of the measures for mitigating the effects of explosions, therefore providing extra care and protection for the human, structure and the necessary equipment that is situated inside the building. The thesis mainly focuses on the dates and information about explosives, blast loading parameters and methods for building design that shows more resistance to blast, by considering safety in both architectural part and structural part. Only a large number of explosives can be caused by high explosions (chemical reactions) are considered within the study. High explosives are mainly confined to explosives, and they are in form of solids. TNT (trinitrotoluene) is the most widely used explosive that causes a blast. There are mainly three kinds of explosions namely, unconfined explosions, confined explosions, and the explosions that are made by the explosives stored or attached to the structure.

The actual mean of facet one of the small flat surfaces cut on a precious stone. In the construction field, a facet is bugging that are provided in walls. Which are provided to reduce the sound effect on conference hall auditorium, etc. facet can be provided in different shapes, the shape is provided accordance with the aesthetic purpose of the room. Different type of materials is used to make the facet it include wood, plaster-of-praise, concrete, etc.

There have been numerous investigations into blast loading of structures using open air charges and under water charges , several studies have investigated dynamic deformations due to explosive blast loading on reinforced concrete structures. Chaochen Zhai et al conduct both experimental and numerical investigation on RC beam subjected to blast loading [1] they concluded that, the peak and residual displacements during blast increased nearly linearly with the fire duration. A. Ghani Razaqpur et al [2] both experiment and numerically proved that the longitudinal reinforcement and and stand -off distance are the main criteria's effect the failure. Aditya Kumar Singh et al [3] theoretically calculate the differnt thye of blast and their load .Wang et al [4] theoretically calculate the response of simply supported steel beam under blast at elevated temperature Hrvoje Draganić [5] conduct study on 4 story concrete frame and they derive method to calculate blast load on structures. Ngo et al [6] investigated the structural stability and integrity of the building by considering the effects of the failure of some perimeter columns, spandrel beams and floor slabs due to blast overpressure.Murtha and Crawford et al [7] suggested that the nominal static diagonal-strength of RC beams be increased by 50%. A three-step explicit numerical method based on the layered Timoshenko beam element approach was proposed by Fang et al. [8,9] to analyse the fire resistance of steel members after explosion. Menkes and Opat et al [10] have shown that a structural member governed by flexure under static loading may fail in shear under high intensity and short duration loads.

This paper aims at investigating the reduction of structural failure by adopting facet structure used in sound proofing mechanism in blast loading by reducing the impact of pressure wave on RC beam. The numerical investigation is conducted using the software AUTODYN by adopting the weight of explosive as 7kg and stand-off distance as 1.5m. The redesign of beam is conducted based on indian standard (IS 456 2000)

2. TEST PROGRAMME

The experiments used in this study is taken from the research paper "Experimental and numerical investigation into RC beams subjected to blast after exposure to fire" done by Chaochen Zhai et al

2.1. Specimen Preparation

The tested RC beams are 2500mmlong with square cross section of 200 mm side length. Fig. 1 shows the details of the beams. The longitudinal reinforcing bars are HRB400 grade. The shear stirrups are HRB235 grade. The longitudinal and shear reinforcement ratio is 1.17% and 0.19%, respectively. The concrete cover depth of the longitudinal bars is 20 mm. The beams were casted with normal strength concrete (NSC) of C30 grade, which was made by PII 42.5R Ordinary Portland Cement and carbonate aggregate. The fineness modulus of fine aggregate (river sand) was 2.6, and the diameter of coarse aggregate (basalt rubble) ranged from 5 mm to 32.5 mm. The detailed mix proportion is given in Table 1.

Table -1: Mix Proportion (kg/m3)

Water	cement	Silica fume	Mineral fine	Fine aggregate	Course aggregate
184	284	44	72	767	1150

The specimens were moistly cured in the moulds for 28 d. Laboratory tests were conducted to get basic material mechanical parameters. The average compressive strength of the 150 mm cubic concrete specimen was 32.40 MPa according to Chinese standard GBJ81-85. The average yield strength of the longitudinal reinforcing bars and stirrups was 540.1MPa (J10 mm), 451.4 MPa (J16 mm) and 492.2 MPa (J6 mm), respectively, whilst the corresponding ultimate strength was 619.4 MPa (J10 mm), 620.5 MPa (J16 mm) and 716.9 MPa (J6 mm).

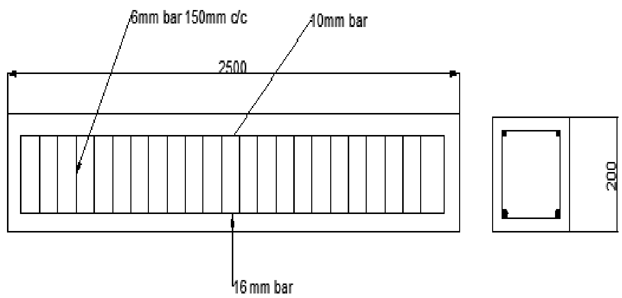


Fig 1- Beam Details

2.2 Measuring Instrument

The WYJL-300 (LVDT) displacement transducers were used to measure the dynamic displacement. The transducers were mounted at even space of 380mmfrom mid-span to the end of the beam.

2.4 Blast Setup

The blast tests on the RC beams were carried out in a specially designed setup, as shown in Fig. 2a. It was constructed in a pit and consisted of the supporting bracket and mounting frame, as shown in Fig. 2b and c. The rock emulsion explosive was hung 1.5 m right above the center of the beam and was detonated to generate blast loadings. Two primer-detonators were placed at the opposite ends along the length of the explosive and were connected in an electric circuit to ensure simultaneous detonation.

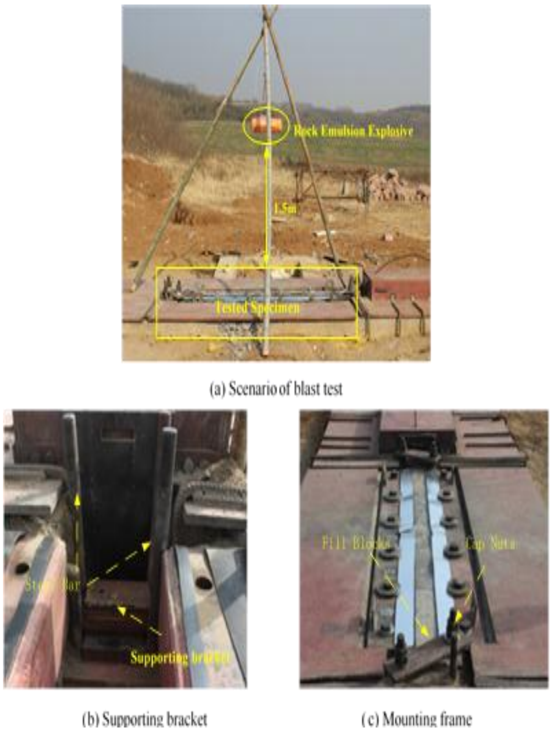


Fig.2- Blast set up

3. TEST RESULTS AND DISCUSSION

3.1. Results of Blast Tests

The dynamic displacement time histories at the gauge point D3 of the beam which was loaded at the upper surface of the beam are plotted in chart -1 that the maximum deformations at the point D3 and the peak dynamic deformation at the mid-span of the tested beam are 25.45 mm, the experiments used in this study is taken from the research paper Experimental and numerical investigation into RC beams subjected to blast after exposure to fire done by Chaochen Zhai and et al

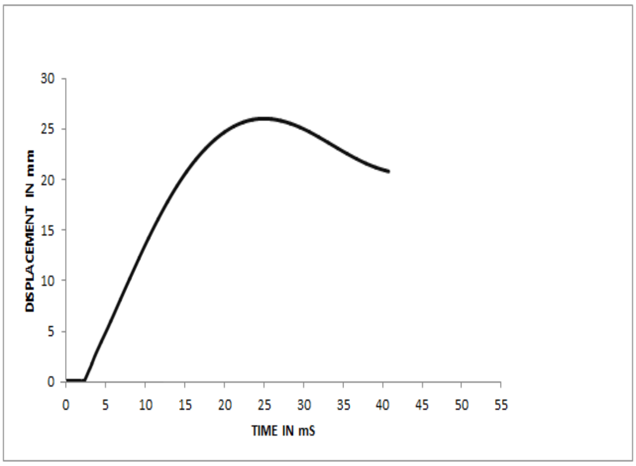


Chart -1 Displacement vs. time graph (Experimental Result)

4. NUMERICAL RESULTS

4.1 FEA Modelling

The experimental setup is recreated in software, and the analysis of experimental result was done. AUTODYN is the software that used for the analysis. The geometry of a beam is done based on an experimental value which is shown in fig.1.The facets are provided on soffits of the beam in actual condition for simplifying the modelling procedure facets are provided on the top face of the beam. Concrete is modelled as solid and reinforcement as line element and the model meshed at an element size of 30 mm. To satisfy the actual support condition four supports of the 50mm radius were modelled and assign it as rigid and fixed. The real boundary condition is neither fixed nor simply supported, which implies that the beam is partially restrained in the vertical direction and no restriction in the horizontal direction. The boundary conditions are adopted from. [1]

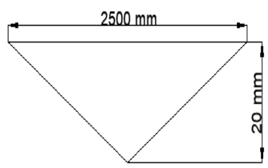
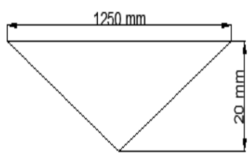
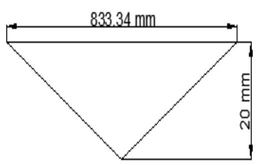
7kg of TNT mass is assigned using map file by converting mass in to the radius and the corresponding radius was 101mm.

Air medium was also created for propagating blast wave, and the air is consider as an ideal gas and corresponding gauges were set in concrete.

The facets are provided in the horizontal direction and eight designed models are created with a different dimension of facets.

The detailed of numerical models are listed in Table -2.

Table 2 -Details Numerical models

model	Facet	Height (mm)	Width (mm)
Control beam	----	----	----
FT-1		20	2500
FT-2		20	1250
FT-3		20	833.34

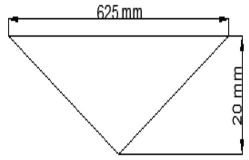
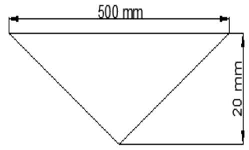
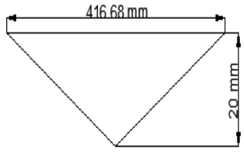
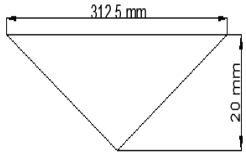
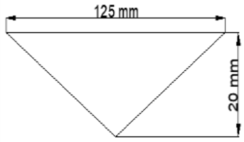
FT-4		20	625
FT-5		20	500
FT-6		20	416.68
FT-7		20	312.5
FT-8		20	125

Fig.3 shows the geometry of control beam and Fig.4 (FT-1 to FT-8) shows the geometry of designed model , where factes are provided in the horizontal direction (The dimension of facets are provided accordance with table 2)

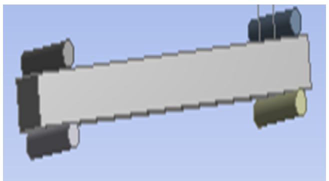
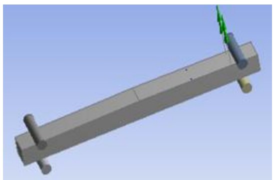
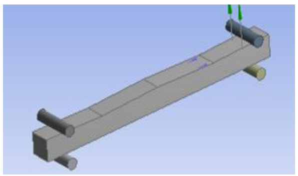


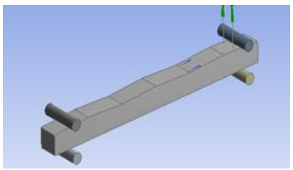
Fig.3 - Geometry of control model



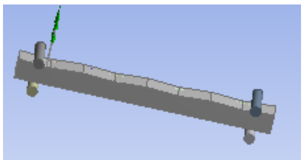
a) Model 1 : FT-1



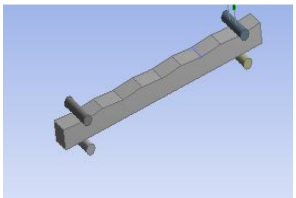
b) Model 2 : FT-2



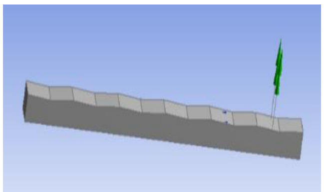
c) Model 3: FT-3



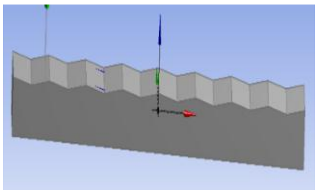
d) Model 4: FT-4



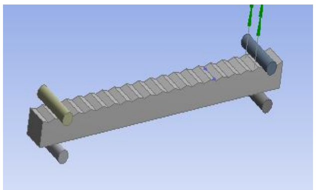
e) Model 5: FT-5



f) Model 6: FT-6



g) Model 7: FT-7



h) Model 8: FT-8

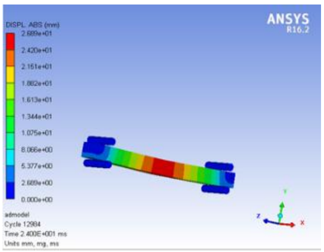
Fig.4- Geometry of Designed models

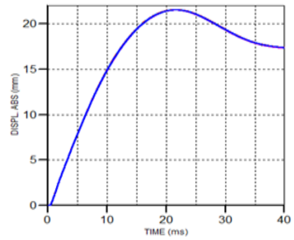
Meshing and analysis steps performed for above models in AUTODYN is similar as that of in control model.

4.2 Result and Discussion

The displacement vs time plots of control beam shown in Fig.5 generally an agreement between the numerical predictions and test data was observed. And the value obtained from numerical simulation is 26.5mm.

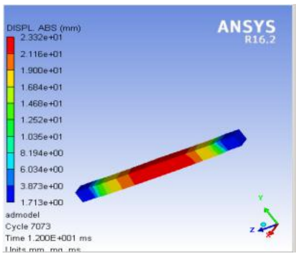
The FEA results and displacement vs time plots of 8 facet beam model were shown in Fig.6

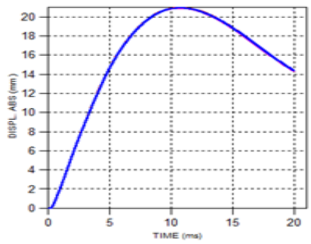




a) FEA Result b) Displacement vs. Time graph

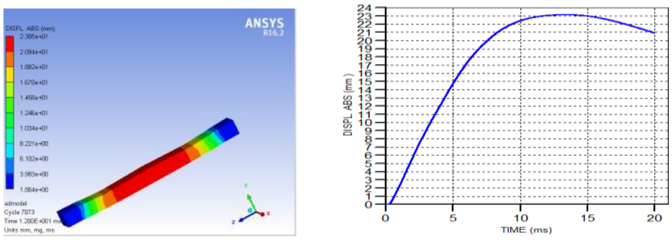
Fig.5- Control Beam





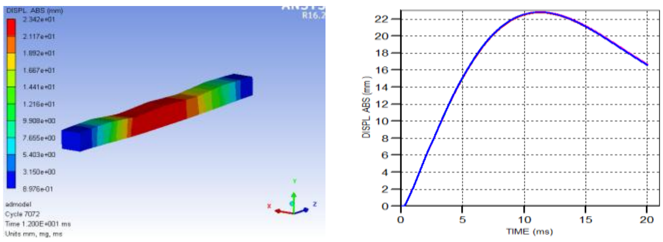
i) FEA Result ii) Displacement vs. Time graph

a) Model 1 - FT-1



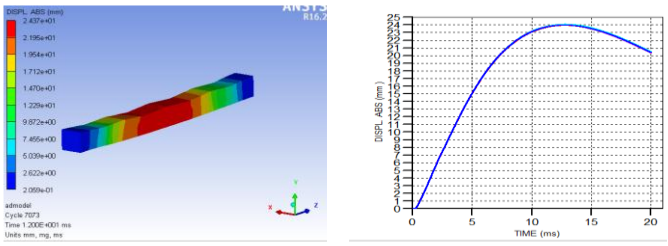
i) FEA Result ii) Displacement vs. Time graph

b) Model 2 - FT-2



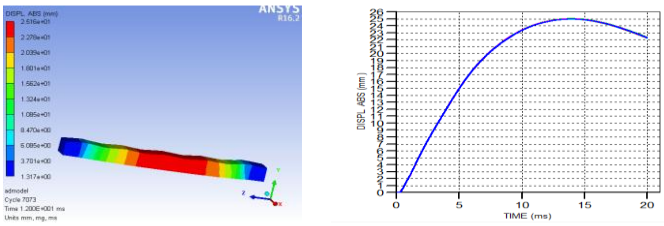
i) FEA Result ii) Displacement vs. Time graph

c) Model 3- FT-3



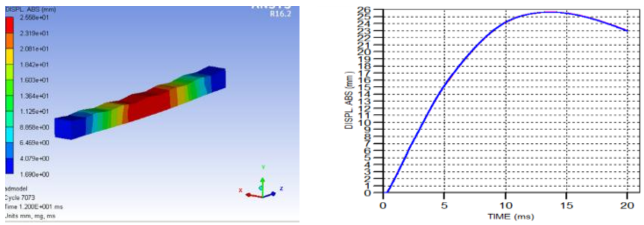
i) FEA Result ii) Displacement vs. Time graph

d) Model 4 - FT-4



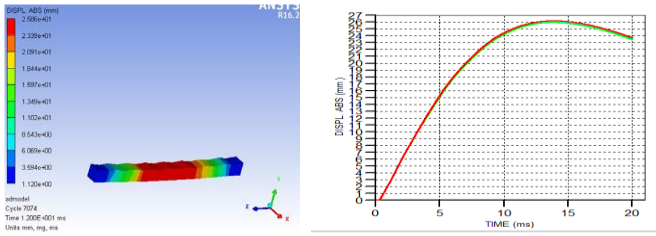
i) FEA Result ii) Displacement vs. Time graph

e) Model 5 - FT-5



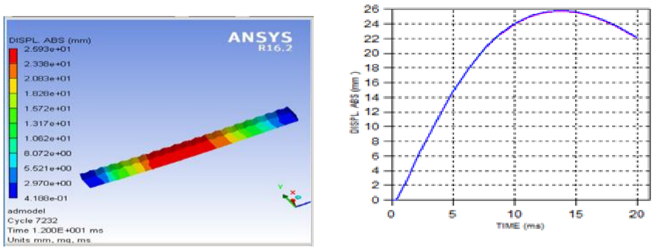
i) FEA Result ii) Displacement vs. Time graph

f) Model 6 - FT-6



i) FEA Result ii) Displacement vs. Time graph

g) Model 7 - FT-7



i) FEA Result ii) Displacement vs. Time graph

h) Model 8 - FT-8

Fig.6-FEA Results and Displacement vs. Time graphs of designed models

The relative peak deformation obtained is 22.5, 23, 23.4, 24.3, 25, 25.5, 25.8 and 25.9mm respectively. The least peak displacement value is obtained for model first 22.5mm which shows the lesser among these designed models. The graphical representation of displacement value of each designed model is shown in chart-2

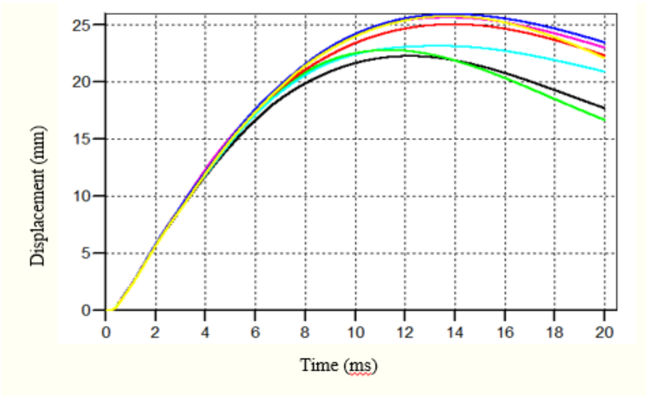


Chart-2 comparison graph for designed models (Displacement vs. Time graph)

5. CONCLUSION

The present work addresses the influence of blast wave on the dynamic response of facet surface of the beam. FEA model was developed in AUTODYN software and compared with the control model. The following conclusions were drawn from the numerical analysis.

The least displacement is shown by the designed model (mode-1 to model-8) when comparing with the base model. The blast waves are reflected back when waves are hitting on facet surface, it is the reason behind a reduction in displacement value. While analyzing the result of numerical simulation of facet models, model 1 shows the least displacement i.e., 22.5mm. Damage occurs mainly near to the support and stress fail to concentrate at the bottom part of the beam.

Further study on the RC Beam subjected to blast should be carried out, with different facets shape by altering the angle. Blast loading stimulation still needs to concentrate the attention of researchers in terms of damage features and strength criterion of a beam.

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ACKNOWLEDGEMENT

The authors wish to gratefully acknowledge the support from the management and staff from CIVIL Department of Federal Institute of Science and Technology, Angamaly.

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