A COMPARISON ON THE EFFECTS OF STEEL JACKETING AND INCREASE OF LONGITUDINAL REINFORCEMENT RATIO ON COLUMNS SUBJECTED TO BLAST LOADING

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Abstract

The recent terrorist attacks worldwide points out the vulnerability of many of the structures to blast loading. Blast loading is basically a shock wave which has detrimental effects on structures and is generated by the detonation of explosives. Columns play a major role in maintaining the structural stability. Hence if columns are not strong in withstanding blast loading the whole structure will collapse. Thus strengthening of column is having such an importance. A design which is resistant to blast loading makes the construction quite expensive. Hence the study of the response of columns to blast loading under various parameters is pertinent since the same can be used to strengthen the columns against blast loading. The column has been modelled using ANSYS Workbench and the response to blast loading has been analysed using ANSYS Autodyn. Explicit dynamics is used to simulate the blast wave propagation. The blast loading resulting from the detonation of Trinitrotoluene is used to study the response of columns.

Index Terms: Blast loading, Trinitrotoluene, Blast wave, Explicit dynamics, ANSYS Autodyn.

I. INTRODUCTION

Over the last decades considerable attention has been raised on the behaviour of engineering structures under blast loading. The terrorist attacks and threats are a growing problem all over the world that not only affect the life of human beings but also affect the structural integrity of the buildings. The terrorist attacks on major buildings can cause catastrophic failure on the structural frames resulting in collapse of the building. Usually the casualties from such a detonation are not only related to instant fatalities as a consequence of the direct release of energy, but mainly to structural failures that might occur and could result in extensive life loss. If the structural failure is not prevented by some means it could lead to increased number of victims and injuries. Famous examples of such cases are the bombing attacks at the World Trade Center in 1993 and on the Alfred P. Murrah Federal Building in Oklahoma City in 1995. Hence in depth understanding is required about the blast phenomenon, propagation of waves towards the structure and also regarding the response of such structure against such shock waves.

Explosives are classified into two: military and civilian explosives. Bombs, bullets, shells and various other plastic explosives which are mainly used for demolition and other special purposes are categorized under military explosives. Military explosives are usually high explosives. Products like dynamite, trinitrotoluene (TNT) and Ammonium nitrate come under commercial explosives. The blast loading effects are usually studied with respect to TNT. Hence other explosives should be defined in terms of TNT to specify the effects of such an explosive. This can be done by relating the explosive energy of the effective charge weight of those materials to that of an equivalent weight of TNT. This is known as TNT equivalency. [1]

In blast loading, the detonation of the explosive is due to the high-rate chemical reaction. In this reaction sudden release of energy occurs. Thus the shock wave on interaction with structures causes detrimental effects on the structures. At the arrival of the shock wave, the overpressure reaches its maximum and it starts decreasing. This phase is known as the compression phase. After decreasing to zero, a negative overpressure occurs which again reaches to zero overpressure. This phase is known as the suction phase. The overpressure during the suction phase is low compared to the overpressure during the compression phase and hence quite often it is ignored [2]. Depending on the confinement, blast loading on structures is broadly divided into confined and unconfined explosions.

The interaction of blast wave with structure is a complex phenomenon. The response of structures subjected to blast loading need detailed study. Luccioni *et al.* [3] analysed the structural failure of a reinforced concrete building which was subjected to blast loading. Numerical analysis of the building was done using AUTODYN software and it was found that the collapse of the building was mainly due to the destruction of the lower columns of the building. Since columns play a major role in the structural stability of the structure, the response of the column when it is subjected to blast loading need to be studied. The various methods by which the column could be strengthened also need to be investigated. In this work, numerical study is conducted to understand the behaviour of columns subjected to blast loading. In this study the columns are strengthened against blast loading by increasing the longitudinal reinforcement ratio and by providing steel jacketing and the response of the columns to blast loading is compared with the conventional one.

II. VALIDATION

The pressure-history for each blast loading mainly depends upon the charge weight and the stand-off distance and hence in many of the softwares it is difficult to simulate the blast loading effects. However, in many of the conventional softwares, analysis of blast loading is done by giving the pressure-time history as an input. For obtaining the pressure-time history some other software should be used which is designed for generating the pressure-time history such as ATBlast. Softwares such as ABAQUS, LS-DYNA and ANSYS-Autodyn are capable of generating the blast wave based on the charge weight of TNT used. In this work, ANSYS Autodyn is used to simulate the blast phenomenon.

ANSYS Autodyn is an explicit analysis tool for modelling nonlinear dynamics of solids, fluids, gas, and their interaction. The Explicit Dynamics system is designed to simulate nonlinear structural mechanics applications involving impact from low (1m/s) to very high velocity (5000m/s) such as stress wave propagation, high frequency dynamic response, large deformations and geometric nonlinearities, complex contact conditions, complex material behavior including material damage and failure, nonlinear structural response including buckling, shock wave propagation etc. Explicit dynamics is most suited to events which take place over short periods of time, a few milliseconds or less.

A. Air Blast Validation

The validation of ANSYS- Autodyn software is done by modelling the blast wave caused by the detonation of 10 kg of TNT and the pressure wave at a distance of 3 m was measured and the results were compared with the results from the literature, “Air Blast Validation Using ANSYS/AUTODYN” by Jha N. and B. S. Kiran [4]. The materials used in the analysis are air and TNT. The 2-D analysis was done here. The air and TNT was modelled as an Euler-2D multi-material. The air was modelled as a wedge and the TNT was filled into the wedge as an elliptic geometrical space having equal semi-axis in X and Y directions. Fig.1 shows the air and TNT model in Autodyn.

The density of TNT is 1.63 g/cm^3. Based on the density, the radius of 10 kg of TNT was calculated and it was modelled in AUTODYN. The detonation point was defined at the origin where the TNT mass occupies the wedge. A gauge point was inserted at 3 m from the origin to record the pressure developed at the point. The cycle limit defined for the analysis was 1000000 and the time limit for the analysis was 5 ms. The pressure developed at the gauge which was placed at 3 m from the origin is shown in Fig. 2.

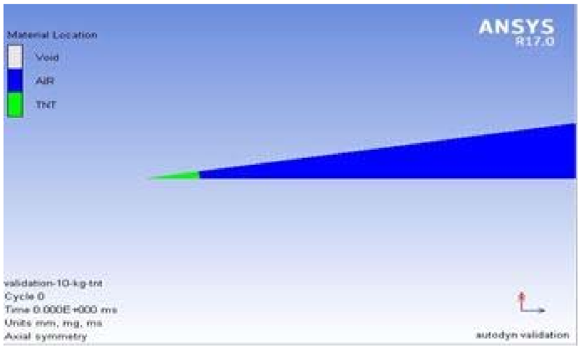

Fig. 1 Modelling of Air and TNT

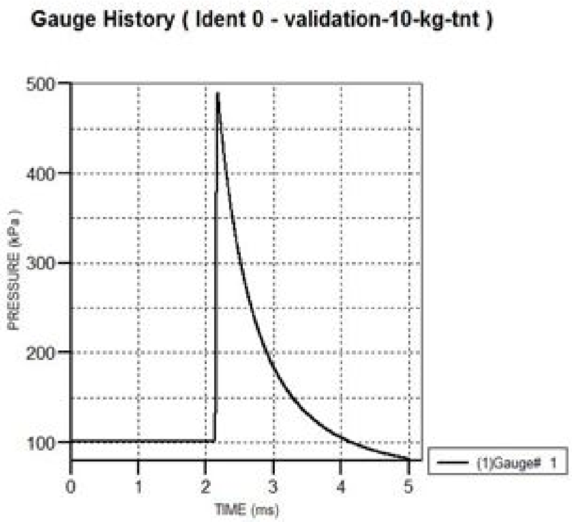

Fig. 2 Gauge Pressure

From Fig. 2, it can be seen that the maximum pressure developed is 492.5 kPa. From the literature, “Air Blast Validation Using ANSYS/AUTODYN” by Jha N. and B. S. Kiran (2014) it is 500 kPa. From validation, the error observed is 1.5 %. Hence it is clear that the software is accurate in the simulation of blast wave. Therefore, ANSYS- Autodyn could be used in the analysis of column subjected to blast loading.

III. FINITE ELEMENT MODELLING

A column of cross section 200 mm x 500 mm has been modelled in ANSYS Workbench using the modelling tools available in the software. Six numbers of longitudinal bars of 16 mm diameter is provided. Stirrups of 6 mm diameter are provided at 300 mm spacing. The axial load acting on the column was considered as 500 kN. The column height is 3 m and is fixed at the top as well as at the bottom.

A. *Element Properties*

The fully coupled model is adopted here. The fully coupled model consists of three parts: detonation of the high explosive, propagation of the blast wave and interaction between the wave and the structure. In this fully coupled approach, the high-explosive materials are modelled by using the Eulerian mesh while the structures are modeled by using the Lagrangian mesh.

B. *Material Properties*

The blast wave interaction with the column is an Euler-Lagrange interaction, hence to simulate the effects air is modelled around the column. A non-reflecting flow-out boundary is used for the Euler domain in the model. In this numerical model the ambient air is assumed to be an ideal gas with internal energy of 2.068 x 10^5 kJ/kg and air density is taken as 1.22 kg/m^3. The material parameters are employed based on the data included in the material library of ANSYS Workbench. Concrete with cube strength of 35 MPa and steel 4340 from the material library are assigned as the material properties. The properties of concrete and reinforcement have been assigned to the modelled column in the mechanical part of ANSYS Workbench. The density of TNT is taken as 1.63 g/cm^3.

Meshing is done in the Mechanical part of ANSYS Workbench. The mesh size used is 100 mm. Luccioni *et al.* [5] studied the effects of variation in mesh size in blast analysis using AUTODYN. They found that 100 mm mesh size is the accurate one, even 500 mm mesh size can be used for doing comparisons in AUTODYN.
The number of elements and nodes for the base model is 642 and 1248 respectively. The meshed column is shown in Fig. 3. After meshing, the model is imported to ANSYS Autodyn. Air is modelled so that it surrounds the column and the detonation point. By remapping technique the blast wave generated from a 100 kg TNT at 0.5 m standoff distance has been simulated. In ANSYS Autodyn, the blast wave is generated in the Autodyn-2D and is saved as a file. Later during the three dimensional modelling in Autodyn, this file is read and the axis of symmetry is mentioned so that it will simulate an air blast which is three dimensional. This method used in Autodyn is known as the remapping technique. For measuring the response of the

column, gauges were inserted. Fig. 3 shows the positioning of gauges on the surface of the column. In Fig.3 the column is surrounded with air.

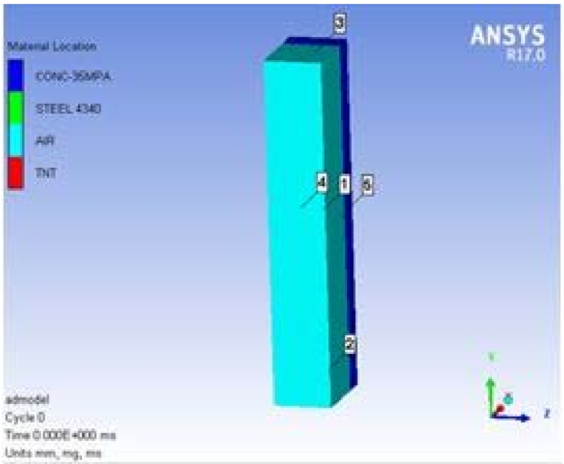

Fig.3 Positioning of gauges on the surface of the column

In this work, displacement is taken as the parameter for comparison. Gauge 1 is placed at the centre of the column on the surface of the column. The reading of Gauge 1 is used to interpret the results as it has given the maximum displacement. As mentioned earlier the TNT is placed at a standoff distance of 0.5 m and the vertical distance of this point from the ground is 1.5m. The time limit for the analysis is 40 ms and the cycle limit is 1000000. The problem gets terminated when either of the time or cycles reaches its limit. In all the analysis the problem was terminated when the time was 40 ms. Thus in this study the response for 40 ms is studied.

IV. RESULTS AND DISCUSSIONS

Blast resistant design results in higher cost of construction. Hence if the response of the structure towards blast loading is studied the results could be used in usual practices. In this study, blast wave is simulated and applied on columns to study the interaction between blast wave and structure for the following cases:

1. Effect of longitudinal reinforcement ratio of columns on the response of columns subjected to blast loading.
2. Influence of steel jacketing on columns under blast loading.

The longitudinal reinforcement ratio was increased from 1% to 4%. Analysis was conducted for 1%, 2%, 3% and 4% of longitudinal reinforcement ratio. The effects of blast loading generated by detonation of 100 kg TNT for a time of 40 ms was studied for each longitudinal reinforcement ratio. The response of the column was studied based on the displacement of the columns. Fig. 4 shows the displacement vs time graph for the different cases.

In Fig. 4, Ident 0, Ident 1, Ident 2, Ident 3, Ident 4 corresponds to longitudinal reinforcement ratios of 1%, 2%, 3%, 4% respectively. The maximum absolute displacement for various longitudinal reinforcement ratio is summarized in Table 1.

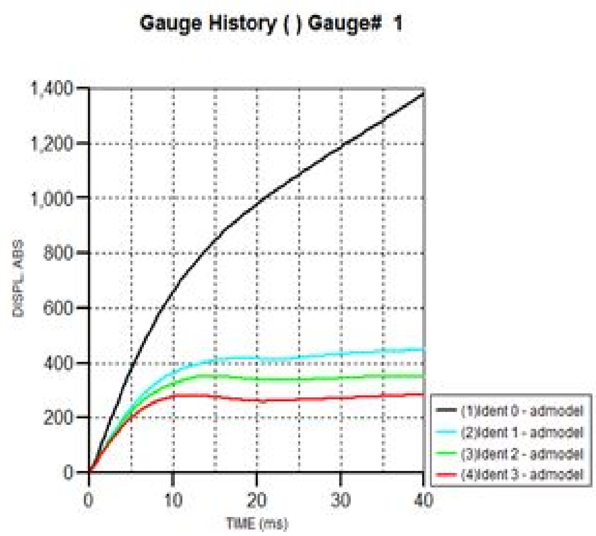

Fig. 4 Comparison of displacement vs time graph for various longitudinal reinforcement ratio

TABLE 1

MAXIMUM ABSOLUTE DISPLACEMENT FOR VARIOUS LONGITUDINAL REINFORCEMENT RATIO

Sl. No.	Longitudinal reinforcement ratio (%)	Maximum displacement (mm)
1	1	1378
2	2	449
3	3	352
4	4	283

It can be seen from Table 1 that as the longitudinal reinforcement is increased there is a reduction in the displacement.

The response of columns was again studied by providing steel jacketing with various thicknesses. Steel jacketing was provided for thickness of 6mm, 8mm and 10 mm. The effects of blast loading generated by detonation of 100 kg TNT for a time of 40 ms was studied for each longitudinal reinforcement ratio. The response of the column was studied based on the displacement of the columns. The response was then studied for the various cases. Fig. 5 shows the displacement vs time graph of gauge 1 for the different cases for a time of 40ms.

In Fig. 5, Ident 0 corresponds to the case of no steel jacketing. Ident 1, Ident 2 and Ident 3 correspond to steel jacketing of thicknesses 6mm, 8mm and 10 mm respectively. The maximum absolute displacement for the various cases is summarised in Table 2.

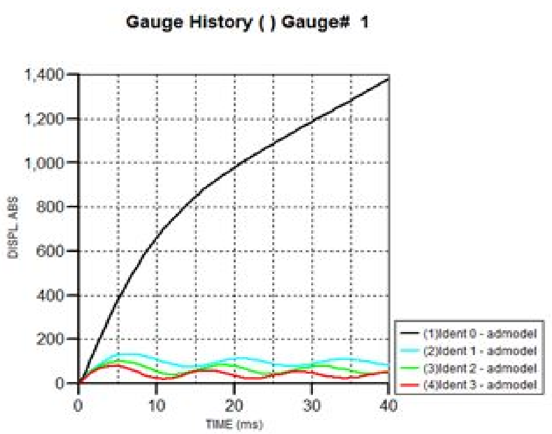

Fig. 5 Comparison of displacement vs time graph for various thickness of steel jacketing

TABLE 2

MAXIMUM ABSOLUTE DISPLACEMENT FOR VARIOUS THICKNESS OF STEEL JACKETING

Sl. No.	Thickness of steel jacketing (mm)	Maximum displacement (mm)
1	0	1378
2	6	133
3	8	100
4	10	79

From Table 2 it is understood that as the thickness of the steel jacketing is increased there is a reduction in displacement.

Thus increasing the longitudinal reinforcement ratio as well as increasing the thickness of the steel jacketing, results in a reduction in the displacement of the columns. Increasing the thickness of the steel jacketing is more effective compared to increasing the longitudinal ratio of the columns.

V. CONCLUSION

The blast wave caused by the detonation of 100 kg TNT at a distance of 0.5 m from the column was simulated using AUTODYN and later it is remapped into the 3-D model done in ANSYS A Autodyn. Increase in steel content in a column increases the ductility of the column and hence it increases the resisting of the column towards blast loading. Whether increasing the longitudinal ratio of the columns or providing steel jacketing is more effective is analysed in this study. It was found that providing steel jacketing around the column is found to be more effective compared to an increase in longitudinal ratio of columns.

VI. ACKNOWLEDGEMENT

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