Blast Loading and Its Effect on Building

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Abstract: When bomb explosion occur near a building causes catastrophic damage to building and danger to human life. It primarily includes damage on external and internal structural frames, crack in beam and column, collapsing of wall, blowing out of windows and shutting down of various life safety systems. Reason for loss of life and injuries to occupants includes direct blast effects, structural collapse, debris impact, smoke and fire. While indirect effect may consider prevention of timely evacuation of occupants, thereby contributing to additional casualties. In addition, explosion occurred in chemical gas plant creates more catastrophic damage to surrounding by generating high frequency blast waves and dynamic loads greater than original design dead loads. Due to threat from such extreme loading conditions, major efforts have been taken in the past four decades to develop structural analysis and design methods to resist blast load. The analysis and design of structure subjected to blast loads require detailed understanding of blast phenomenon and the dynamic response of various structural elements. In the paper response of RCC column subjected to same axial loads and lateral blast loads was studied. The finite element software ANSYS AUTODYN used to model RCC column of high strength and normal strength is considered. For generating response same axial load was applied to column and equilibrium state is determined. Further short duration blast load was applied and deflection-time response and directional deformation was calculated.

Keywords: ANSYS, Axial load, Blast load, Deflection, Directional Deformation, RCC Column.

I. INTRODUCTION

When an explosion happens, it shows the devastating fast discharge of energy in the surrounding atmosphere showing appearance of illumination, heat, resonance and shock wave, where, shock wave consists of high amount of compacted air. When this wave reflects to the earth it creates a semi-circular prolife of that wave which emits from the origin or starting place of explosion at supersonic velocities.

The loading condition like short-duration with high-amplitude significantly affects the structural behaviour that has been seen from the boundless studies of last four decades. Earthquake induced loads are approximately 1000 times slower than that of the explosives loads which are generally applied to the structures. So that structural frequencies obtained by conventional loads are smaller than that of explosive loads.

In past decades explosion made by terrorist creates disasters like bombing in Nairobi, Kenya and Dar es Salaam, Tanzania in 1998, the Khobar towers military barracks in dehran, Saudi Arabia 1996, Murrah federal building in Oklahoma city in 1995, WTC attack in new york in 1993, car bomb attack in oslo, Norway in 2011 etc. illustrates need for examination of behaviour of column under blast loads. To provide ample protection to structure against explosion, the buildings prone to explosion damage are receiving attention from structural engineer. Some difficulties arises with the complexity of the problem, which includes time dependent finite deformation, non-linear inelastic material behaviour and high strain rates have suggested various approximations and assumptions to simply the models further. These models transfer the full range of sophistication from single degree of freedom system to finite element programs such as ANSYS AUTODYN, ABAQUS and LS-DYNA etc.

II. EXPLOSIVE AIR BLAST LOADING

The damage from a conventional explosive is determined from two equally important elements, the explosive size or charge weight *W* and the standoff distance (R) between the blast source and target. As terrorist attacks generally range from the small letter bomb to the gigantic truck bomb as experienced in Oklahoma City, the mechanics of a conventional explosion and their effects on a target must be addressed.

In whole period of explosion mainly two phases can be observed in pressure-time profile, portion above ambient pressure is called positive phase duration (t_d), while portion below ambient pressure is called negative phase duration (t_d). The negative pressure is of smaller in magnitude and lasts for longer duration. As the distance of charge from target increases, the duration of positive phase blast wave increases resulting in lower amplitude and longer duration of shock pulse. Charge placed at very nearer to target, it imposes a highly impulsive, high intensity pressure over localised region of the structure. Whereas charge placed far away from target produces a lower intensity, longer duration uniform pressure distribution over structure. Eventually, the entire structure is engulfed in the shock wave, with reflection and diffraction effects creating focusing and shadow zones in a complex pattern around the structure. During the negative phase, the weakened structure may be subjected to impact by debris that may cause additional damage.

STANDOFF DISTANCE – It is horizontal distance between explosion point and the structure under consideration to determine blast effect.

HEIGHT OF BURST – It is distance between explosive charge in free air and target under consideration.

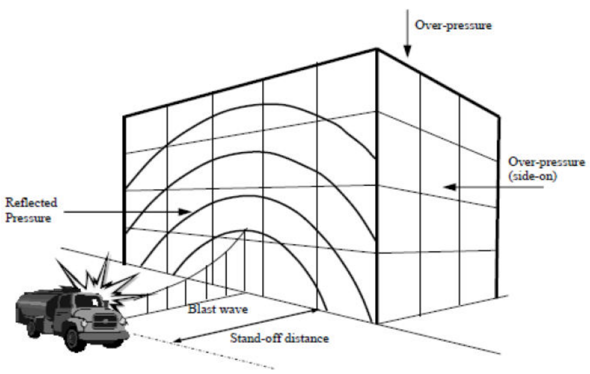


Fig.1 Blast Loads on a Building

III. Prediction of Blast pressure

Blast wave parameter for conventional high explosive materials have been the focus of a number of studies during the 1950's and 1960's.

The estimations of peak overpressure due to spherical blast based on scaled distance Z= $R/w^{1/3}$ was introduced by Brode (1955) as:

$$P_{so} = 6.7/z^3 + 1\text{bar} \ \ldots\ldots \ (P_{so} > 10\text{bar})$$

$$P_{so} = 0.975/z + 1.455/z^2 + 5.85/z^3 - 0.019 \text{ bar}$$

Where, (0.1< Pso < 10 bar)

In 1961, Newmark and Hansen introduced a relationship to calculate the maximum blast pressure (Pso), in bars, for a high explosive charge detonates at the ground surface as:

$$P_{so} = 6784\,(W/R^3) + 93\,(W/R^3)^{1/2}$$

In 1987, Mills introduces another expression of the peak overpressure in kpa, in which W is the equivalent charge weight in kilograms of TNT and Z is the scaled distance.

$$P_{so} = 1772/z^3 - 114/z^2 + 108/z$$

As the blast wave propagates through the atmosphere, the air behind the shock front is moving outward at lower velocity. The velocity of the air particles, and hence the wind pressure, depends on the peak overpressure of the blast wave. This later velocity of the air is associated with the dynamic pressure, q (t). The maximum value, $q(s)$, say, is given by

$$q(s) = 5\,Pso^2/2\,(Pso+7\,Po)$$

If the blast wave encounters an obstacle perpendicular to the direction of propagation, reflection increases the overpressure to a maximum reflected pressure P_r as:

$$P_r = 2Pso\left\{\frac{7Po+4Pso}{7Po+Pso}\right\}$$

A full discussion and extensive charts for predicting blast pressures and blast durations are given by Mays and Smith (1995) and TM5-1300 (1990). Some representative numerical values of peak reflected overpressure are given in Table below:

Table 1- Peak reflected overpressure with different W-R combination

W / R	100Kg TNT	500Kg TNT	1000Kg TNT	2000Kg TNT
1m	165.8	354.5	464.5	602.9
2.5m	34.2	89.4	130.8	188.4
5m	6.65	24.8	39.5	60.19
10m	0.85	4.25	8.15	14.7
15m	0.27	1.25	2.53	5.01

20m	0.14	0.54	1.06	2.13
25m	0.09	0.29	0.55	1.08
30m	0.06	0.19	0.33	0.63

IV. Structural Response TO BLAST LOADING

Blast load generally acts for shorter duration so it also called as impulsive loading. Mathematically it is considered as triangular loading. The response of structure to an explosion depends on ductility and natural vibration period.

Ductile elements such as steel, RCC can absorb more amount of energy as compare to brittle material like masonry, timber, glass which fails suddenly. To determine dynamic response of structure following procedure is followed.

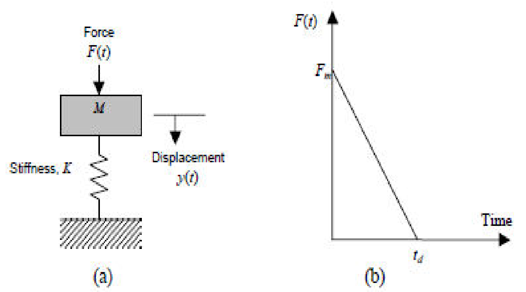


Figure 2 (a) SDOF system and (b) blast loading

(a) The characteristics of blast wave must be determined;

(b) The natural period of response for structure must be determined;

(c) Now positive phase of blast wave must be compared with natural period of response for structure.

Based on (c) response of structure classified as follows;

• Impulsive – Positive phase duration of blast wave is shorter than natural period of response. In this, most of deformation occurs after blast wave diminishes.

• Quasi-static – Positive phase duration of blast wave is longer than natural period of response. In such case, deformation occurs when load is being applied.

•Dynamic – Positive phase duration of wave is nearer to natural period of response. In this case deformation is function of time and response of structure calculated by solving the equations of motion.

The equation of motion of the un-damped elastic SDOF system for a time ranging from 0 to the positive phase duration, *td*, is given by

$$M\ddot{y} + Ky = F_m\left\{1 - \frac{t}{td}\right\}$$

The general solution can be expressed as:

$$\text{Displacement } y(t) = \frac{Fm}{K}(1-\cos\omega t) + \frac{Fm}{Kd}\left\{\frac{\sin\omega t}{\omega} - t\right\}$$

$$\text{Velocity } \dot{y}(t) = \frac{dy}{dx} = \frac{Fm}{K}\left[\omega \sin\omega t + \frac{1}{td}(\cos\omega t - 1)\right]$$

Where, ω = natural circular frequency of vibration of the structure and *T* = natural period of vibration of the structure

$$\omega = \frac{2\pi}{T} = \sqrt{\frac{K}{M}}$$

The maximum response is defined by the maximum dynamic deflection *ym* which occurs at time *tm*. The maximum dynamic deflection *ym* can be evaluated by setting *dy*/*dt* in Equation 12 equal to zero, i.e. when the structural velocity is zero. The dynamic load factor, DLF, is defined as the ratio of the maximum dynamic deflection *ym* to the static deflection *yst* which would have resulted from the static application of the peak load *Fm*, which is shown as follows:

$$DLF = \frac{Ymax}{Yst} = \frac{Ymax}{Fm/K} = \psi(\omega.t_d) = \psi\left(\frac{td}{T}\right)$$

V. Methodology

In order to suggest strategy a structure which could perform satisfactorily against accidental explosions and analytical studies were conducted using ANSYS 19 to study deflection behaviour of structure.

The typical procedure is given in following chart:

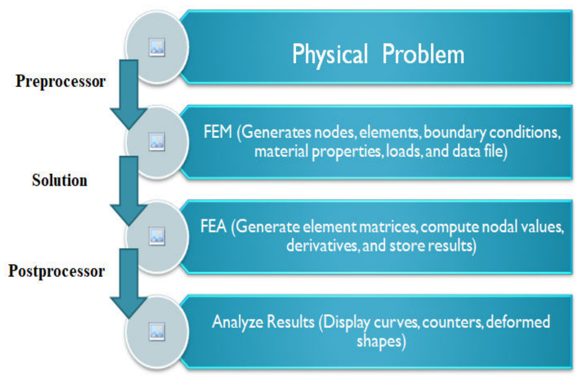


Fig.3 Flow Chart

The pre-processor is a program that processes the input data to produce the output that is used as input to the subsequent phase (solution). Following are the input data that needs to be given to the pre-processor:

1. Type of analysis (structural)

2. Element type

3. Real constants

4. Material properties

5. Geometric model

6. Meshed model

7. Loadings and boundary conditions.

The input data will be pre-processed for the output data and pre-processor will generate the data files automatically with the help of users. Solution phase is completely automatic. The FEA software generates the element matrices, computes nodal values and derivatives, and stores the result data in files. The output from the solution phase (result data files) is in the numerical form and consists of nodal values of the field variable and its derivatives. The post processor processes the result data and displays them in graphical form to check or analyse the result.

● Implicit Dynamics:

In static analysis, there is no effect of mass (inertia) or of damping. This Static analysis is done using an implicit solver in ANSYS LS-DYNA. In nonlinear implicit analysis, solution of each step requires a series of trial solutions (iterations) to establish equilibrium within a certain tolerance. Implicit transient analysis has no inherent limit on the size of the time step. As such, implicit time steps are generally several orders of magnitude larger than explicit time steps. Implicit analysis requires a numerical solver to invert the stiffness matrix once or even several times over the course of a load/time step. This matrix inversion is an expensive operation, especially for large models.

● Explicit Dynamics:

The Ansys explicit dynamics suite enables to capture the physics of short duration events for products that undergo highly nonlinear, transient dynamic forces. These specialized, accurate and easy-to-use tools have been designed to maximize user productivity. With Ansys, one can gain insight into how a structure responds when subjected to severe loadings. Algorithms based on first principles accurately predict complex responses, such as large material deformations and failure, interactions between bodies, and fluids with rapidly changing surfaces.

In many cases, the accuracy of an explicit solution can be verified only via comparison with physical experiments. For some problems (such as explosions), it may be too expensive or impossible to perform tests. Yet Ansys users around the world rely on the accuracy of explicit results; an extensive list of publications is testament to the correctness of our algorithms and models. Ansys explicit dynamics tools help engineers to explore a wide range of challenges.

- Quasi-static.
- Material failure.
- Material fragmentation.
- Penetration mechanics.
- Space debris impact (hyper velocity).
- Sports equipment design.
- Drop-test simulation.
- Explosive loading.
- Explosive forming.
- High-speed and hyper velocity impacts.
- Severe loadings resulting in large material deformation.
- Manufacturing processes with nonlinear plastic response.
- Blast–structure interactions.

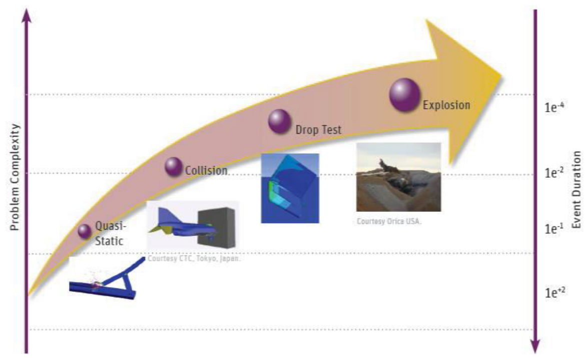


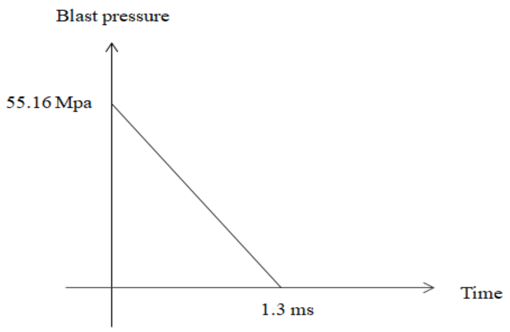
Fig.4 Explicit tool used for various problem and their complexities

VI. Case Study: Column Subjected to Blast Loading

A column situated at ground floor of height 4.5m of multi-storeyed building was analysed in this study. The specifications were considered as 35Mpa for normal strength column (NSC) and 80Mpa for high strength column (HSC) and stirrups spacing of 300mm for

ISSN: 2582-3930

ordinary detailing and 100mm for seismic detailing for both type of column was taken. From experimentation it has been found that with increase in compressive strength of concrete, the column size reduces significantly. For same axial load column size of 400 × 850mm reduced to 300 × 650mm. The blast loading on column calculated from standoff distance of 6m.The simplified triangle shape of blast load profile was used. The duration of blast wave is 1.3 milliseconds, it only includes positive.



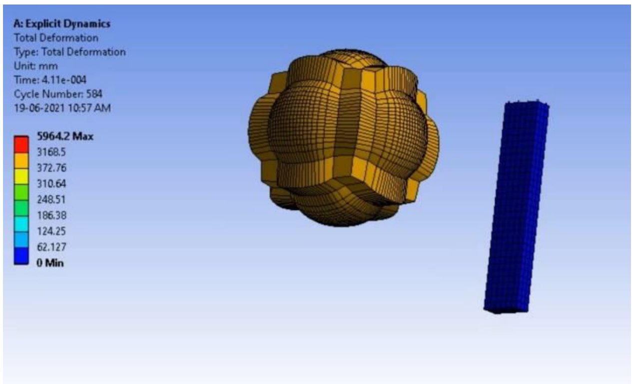


Fig. 5 3D Modelling of column subjected to blast load

VII. Results

- **Lateral Deformation:**

The lateral deflection at mid-point (mm) v/s Time (ms) for NSC and HSC column is shown in fig.6&7 It can be seen that under closed range bomb blast both column fails in shear. It also seen from results that effect of shear reinforcement is more significant in resisting lateral deformation. The ultimate lateral displacement in case of failure for NSC column varies from 28mm (300mm stirrups spacing) to 39mm (100mm stirrups spacing). Those values for HSC column varies from 52mm (300mm stirrups spacing) to 65mm (100mm stirrups spacing).

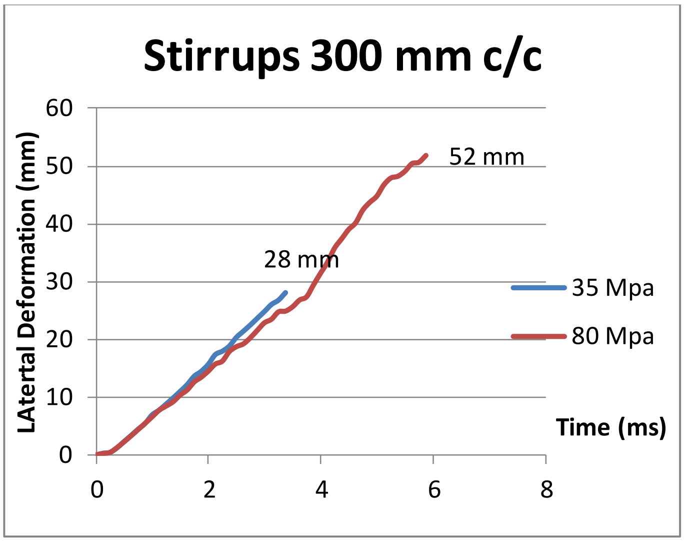


Fig. 6 Lateral deformation for 300mm c/c spacing

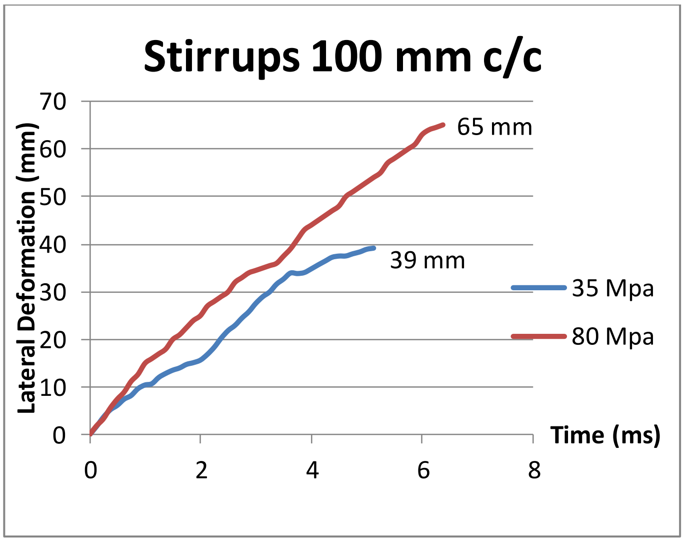


Fig. 7 Lateral deformation for 100mm c/c spacing

- **Directional Deformation:**

The directional deformation in X axis v/s time graph shown in fig.8 from result it can be observed that deformation along X-axis is near about zero because overpressure from both side of structure nullifies the result of directional deformation.

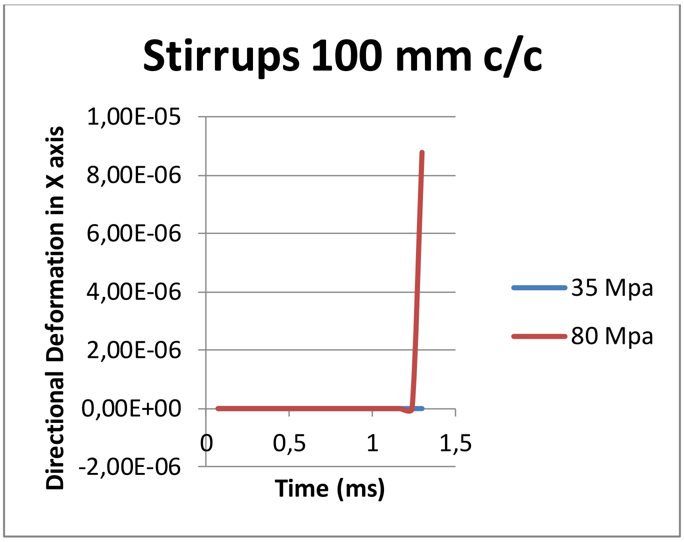


Fig. 8 Directional deformation for 100mm c/c spacing

VIII. Conclusion

Following are the conclusion made from given study:

1) The effect of blast pressure on column is decreases with increase in standoff distance.

2) By using finite element software, it is easy to find behaviour of structure subjected to blast loading by generating mesh and number of cycles to find displacement of structure.

3) The column response to variable blast load for high strength and normal strength column was studied.

4) The structure subjected to blast load cannot be fully protected but it can make stronger to resist blast load by improving grade of concrete and steel quantity.

ACKNOWLEDGMENT

I wish to express my sincere gratitude to Prof. S.L.Hake for his excellent guidance, perennial encouragement and support throughout duration of project. I truly appreciate and value his profound knowledge, esteem supervision and encouragement from beginning to end of this thesis.

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