Analysis of 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 this dynamic loading condition, major efforts have been taken in the past few decades to develop method for structural analysis and to resist blast load. To analyse and design structure subjected to blast impact needs detailed understanding of blast occurring phenomena like intensity, standoff distance and dynamic behaviour of structural member. 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 profile 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

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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 surrounded by the shock wave, with reflection and diffraction effects creating focus zone and shadow zones in a complex pattern around the structure. During the negative phase, debris may impact the weakened structure and cause additional damage.

STAND OFF 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.

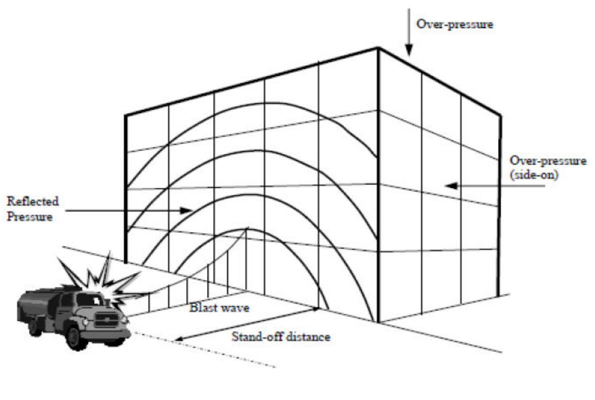

Fig.1 Blast Loads on a Building

III. PREDICTION OF BLAST PRESSURE

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

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

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

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

Where, (0.1< Pso < 10 bar)

In 1961, Newmark and Hansen introduced a equation to find the maximum blast pressure (Pso), in bars for a high explosive charge weight explodes at the ground surface as:

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

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

$$P_{so} = {}^{1172}/_{Z^3} - {}^{114}/_{Z^2} + {}^{108}/_{Z}$$

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

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

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

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

A full described and extensive chart 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 for different charge weight and standoff combinations 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

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 used.

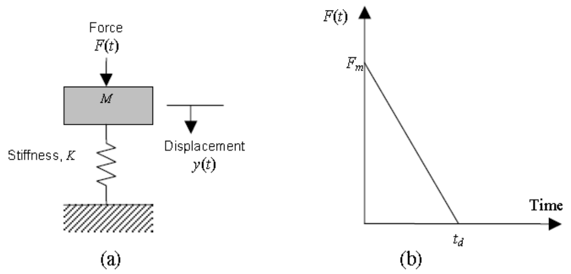

Figure 2 (a) SDOF system and (b) blast loading

(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 for undamped elastic SDOF system for a time ranging from zero 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:

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

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 the maximum dynamic deflection *ym* which occurred in time *tm*. The maximum dynamic deflection *ym* can be evaluated by setting *dy*/*dt* in displacement equation is 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 displacement (*ym*) to the static displacement (*yst*) which would have calculated from the static application of the peak of triangular loading (*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:

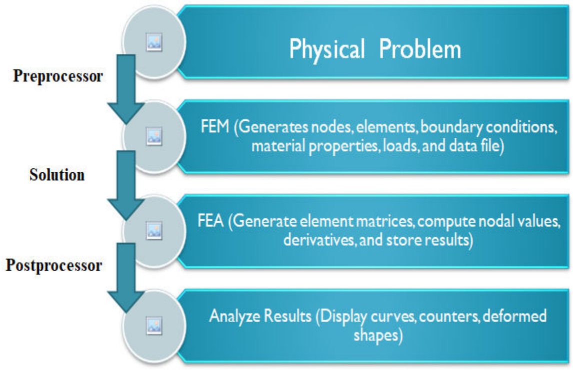

Fig.3 Flow Chart

The pre-processor is a program that processes the input data in system to produce the output of function that is used as input to the successor phase (solution). Following are the input data that should 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 must be pre-processed for the output data and pre-processor will generate the data files automatically with the help of users. Successor phase (solution) is completely automatic. The FEA software generates the finite element matrices, computes nodal values of function and derivatives, and stores the output data in form of files. The output generated from solution phase (result data files) is preferably a numerical data and consists of nodal values of the field variable and its derivatives. The post-processor processes the result data and shows in form of graphical data to perform check to it or analyse the result.

● **Implicit Dynamics:**

In static analysis, there is no effect of mass moment of inertia or damping. This Static analysis is done using an implicit solver in ANSYS LS-DYNA. Solution of each step requires a number of trial solutions or iterations in nonlinear implicit analysis to determine equilibrium within a specified tolerance. Implicit transient analysis has no immanent limit on the size of the time space. As such, implicit time spaces are generally several times more than magnitude of explicit time space. Implicit analysis requires a numerical solver to transform the stiffness matrix once or even several times over the course of a load/time space. This matrix transformation is an expensive operation, especially for large models.

● **Explicit Dynamics:**

In ANSYS explicit dynamics system helps to capture shorter duration of physical events that creates highly nonlinear, transient dynamic forces. This is so specialised, accurate and easy to use tool design to maximize productivity of user. Using ANSYS explicit tools, one can get idea about how a structure responds when subjected to high intensity loading for shorter duration. Algorithm of such tool accurately predicts complex responses, such as large material deformations and failure, sudden impact between two bodies and fluid with rapidly changing surfaces.

In most of cases, feasibility of an explicit dynamics tool can be checked only by comparing with physical experiments. For problems like explosion, it may be too expensive or impossible to perform physical tests. Yet ANSYS users around the world rely on the accuracy of explicit tool and considers for design purposes.

Ansys explicit dynamics tools helps engineer to deal with a wide range of problems like

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

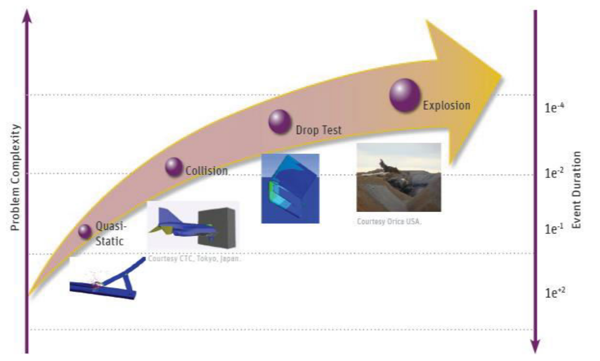

Fig.4 Explicit tool used for various problem and their complexities

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 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.

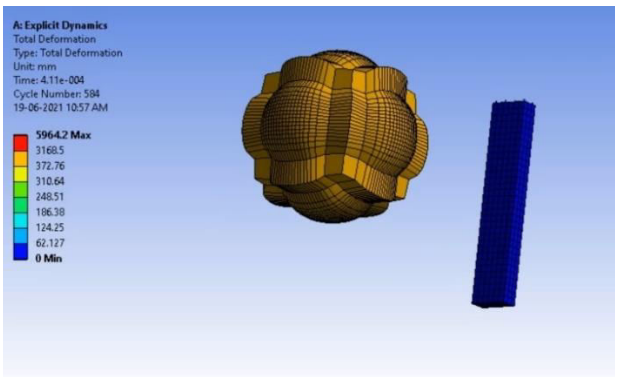

Fig. 5 3D Modelling of column subjected to blast load

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).

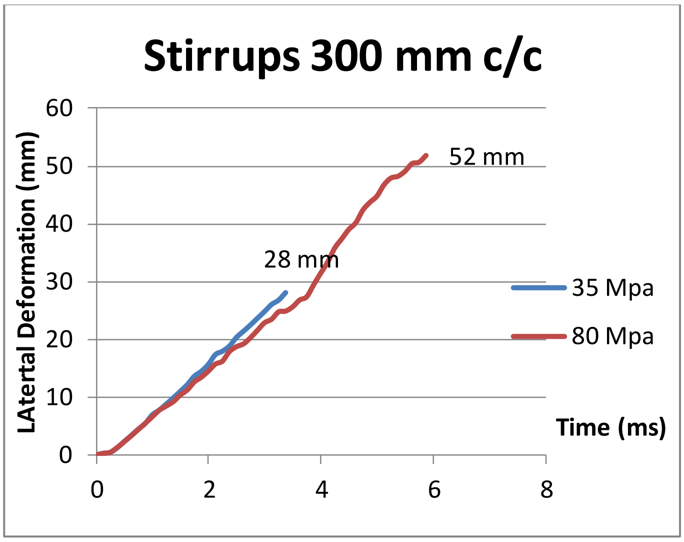

Fig. 6 Lateral deformation for 300mm c/c spacing

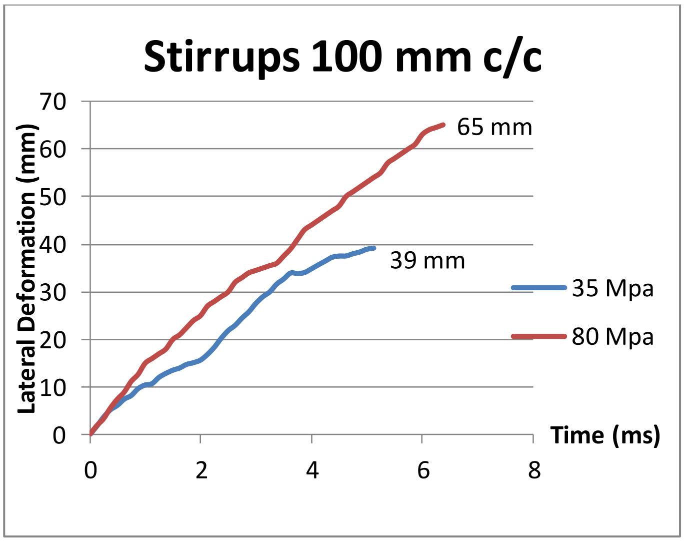

Fig. 7 Lateral deformation for 100mm c/c spacing

• 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.

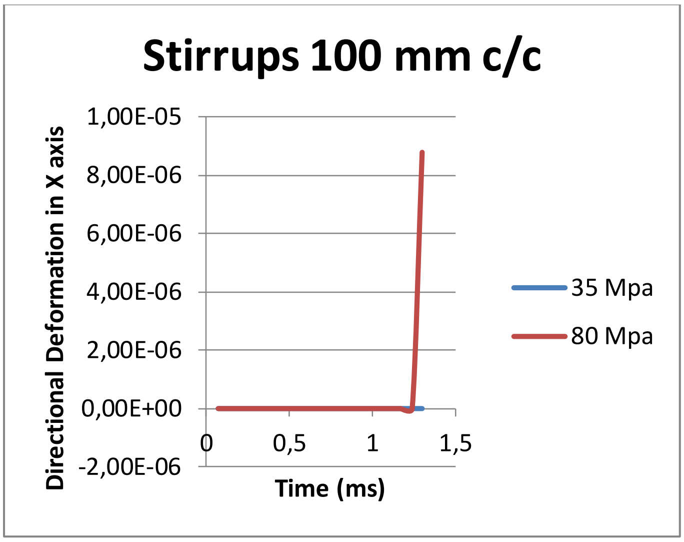

Fig. 8 Directional deformation for 100mm c/c spacing

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 use of lateral ties in column at shorter spacing is more significant to minimize damage due to blast load.
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.

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