Prediction of blast loading and its effect on RCC structures

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Abstract - *Blast attacks by terrorists and other explosive accidents cause damages to structure and impart fatal effect on lives. Hence it is important to design structures that are blast resistant especially in areas where there are chances of blasting. In this project we are concerned about studying in depth the dynamic propagation of blast, quantifying the load caused by blast, Modeling of RCC building and Analysis of the building after application of the blast effect. The loads are calculated manually using methods instructed by UFC 3-340-02, then analyzed and designed in ETABS. Here UFC 3-340-02 is used to study and determine the Blast load parameters since it produces more accurate values and delivers economic construction when compared to IS 4991 1968.*

Key Words: **Blast load, Blast wave, TNT Equivalency, Dynamic analysis**

1.INTRODUCTION

Blast attacks have become a concern due to their increased frequency. Blast loads are extreme, instantaneous, unpredictive impulses acting over milliseconds. This dynamic nature of blast loads has created a challenge to structural engineers all around the world about the deficiency in the design process. Moreover, the field of blast- and impact-resistant design is not as developed as other fields, such as seismic-resistant design. The study includes information about dynamic nature of explosion, calculation of blast loading parameters and enhancements for blast resistant design of a multi-storied building. The provisions for dealing with blast load is done using IS 4991:1968 - Criteria for Blast Resistant Design of Structures for Explosions above Ground and United States of America, Department of Army, Army Corps of Engineers. Unified Facilities Criteria (UFC).

1.1 Blast Loads

The main sources of blast load are High Explosives, Vapour cloud explosions, Pressure vessel explosions etc. Blast loading consists of earth shock, pressure due to blast and effects of debris or fragment whereas blast loading in the distant areas consists of pressure generated due to blast only.

1.2 Blast wave

The release of energy from the detonation propagates radially into the surrounding atmosphere in the form of a shock wave and shock front is termed as blast wave. In the case of air burst as the shock wave propagates reflected waves are also produced, a front commonly called Mach stem is caused due to the interaction of initial blast waves and reflected blast waves. In surface burst explosions the initial shock waves is reflected and amplified by ground surface to produce reflected waves, but here the reflected waves merges with the incident wave at the point of detonation and form a single wave.

1.3 Blast wave Propagation

The shock front arrives at a given location at time arrival time 't_A' and after this rise to the peak value 'P_{SO}' the incident pressure decays to the ambient value in time 't_o', which is the Positive phase Duration. This is followed by Negative phase with time duration greater that positive phase but pressure less than that of the Positive phase duration and is of less importance.

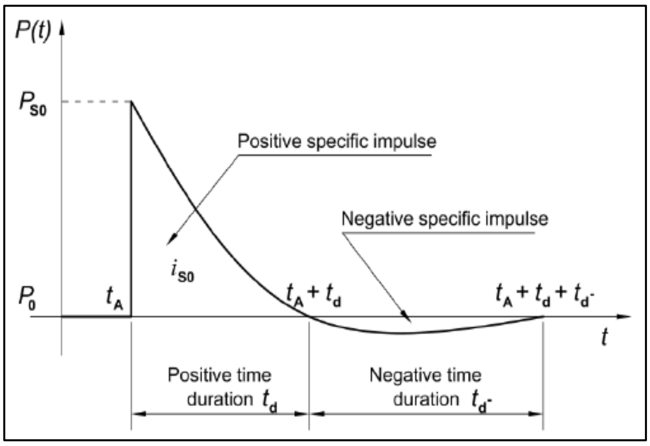

Fig-1: Blast wave Pressure-Time History graph

1.4 TNT equivalency

TNT equivalent is a convention for expressing energy released in an explosion. This convention intends to compare the destructiveness of an event with that of traditional explosive material of which TNT is a typical example, although other conventional explosives contains more energy.

$W_{TNT} = (\Delta H_{EXP} / \Delta H_{TNT}) \times W_{EXP}$

Where W_{TNT}- effective charge weight of TNT, W_{EXP} – weight of explosive, ΔH_{EXP}- Heat of detonation explosion, ΔH_{TNT}- Heat of detonation of TNT.

A blast of 2864lbs of RDX was considered whose W_{TNT}=3300lbs(1500kg).

1.5 Indian And American Codal Provisions

IS 4991-1968 which provides criteria for design of blast resistant structures for explosion above ground doesn't distinguish between Explosion on ground (Hemispherical wave) and Explosion on Air (Spherical wave) and there is variation in blast parameters especially when standoff distance is short.

Unified Facilities Criteria (UFC 3-340-02) is an updated version based on TM5-1300.[13] The Indian Standard Code in terms of peak pressures gives significant high values at shorter standoff distance compared to the ones obtained from UFC 3-340-02.

2. BLAST LOAD CALCULATION

To determine accurately the overall loading on a surface, step-by-step analysis of the wave propagation across the surface was made. This analysis includes an integration of the pressures at various points on the surface and at various times to determine the equivalent uniform incident pressure acting on span L as a function of time.

The following steps were taken for calculating the blast loading on structural surfaces.

Step 1: For a surface blast (RDX) of charge weight W=3300 lbs and standoff distance= 20 m, determine the charge distance R_H and charge height H_C for each panel.

Step 2: Determine the scaled distance, $Z = R_H/W^{1/3}$ For each panel the angle of incidence is $\alpha = \tan^{-1}(H_C/R)$

Step 3: Select the midpoints of each panel on the front façade, roof, side and rear surface. Read the following explosion parameters for each selected point using fig. 2

a) Peak initial positive overpressure P_{SO}(psi)

b) Peak reflected overpressure P_r(psi)

c) Scaled initial positive impulse $I_s/W^{1/3}$ (psi-ms/lb$^{1/3}$)

d) Scaled value of the wave arrival $t_a/W^{1/3}$ (ms/lb$^{1/3}$)

e) Scaled positive phase duration $t_o/W^{1/3}$ (ms/lb$^{1/3}$)

f) Scaled positive reflected impulse $I_r/W^{1/3}$ (psi-ms/lb$^{1/3}$)

g) Scaled positive phase wavelength $L_W/W^{1/3}$(ft/lb$^{1/3}$)

To obtain absolute values multiply the scaled values with $W^{1/3}$

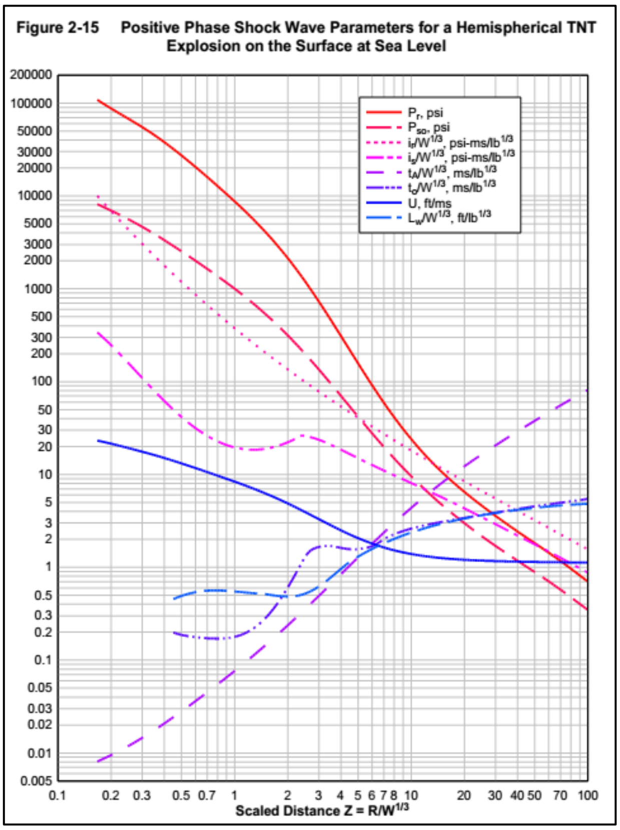

Fig-2: Shock wave parameters for hemispherical TNT explosion

Step 4: The blast parameters obtained can be verified by the following expressions

a) If P_{so}< 40psi, Initial Peak reflected overpressure $P_r = (2+0.05P_{so})P_{so}$

b) Positive impulse $I_s = 0.5(P_r - P_s)t_c + 0.5P_s t_o$

c) Positive phase wavelength $L_W = Ut_o$

Step 5 : For the front façade:

a) Read the reflected pressure coefficient C_{ra} from fig. 2-193, from [6] and calculate the peak positive reflected pressure P_{ra} using the formula:

$P_{ra} = C_{ra} \times P_{so}$

b) Determine the exact positive reflected impulse, I_{ra} from fig. 2-194b, [6] and hence obtain the exact fictitious length of reflected pressure using the formula:

$t_{rf} = 2i_{ra}/P_{ra}$

c) Define the pressure-time history curve for positive phase

Step 6: For the side, roof and rear surface:

a) Determine the ratio of wavelength and the range, L_W/L

b) Read the values of Uniform Pressure factor C_E from fig. 2-196, [6]

c) Using the peak incident pressure interpolate the value of peak dynamic wind pressure q_o from fig. 2-3, from [6]

d) Drag coefficient C_d is determined from handbook for blast resistant design of buildings table 7.1

e) The maximum peak overpressure P_R is determined using the equation:

$P_R = C_E P_{SO} + C_d q_o$

f) Calculate the total positive phase duration:

$t_o = t_d + t_f$

3. DYNAMIC ANALYSIS OF STRUCTURE IN ETABS

Exterior panels were provided for the structure and each panel was named and numbered according to the face of exposure to the blast. Time history function was defined for panel considering the arrival time(t_a), rise time(t_d) and duration of positive phase (t_{of}) for peak reflected pressure. Peak reflected pressure (P_r) was assigned to every panel as uniform shell load in proper directions. Impact due to the explosion was assigned to corresponding sections in KN/m^2. Thus dynamic blast load was applied to the RCC structure in ETABS as a pulse load. Analysis of the structure was done and design check for blast combination and default combinations were done.

3.1 Modeling and Analysis

The beam column layout was plotted according to the architectural plan. Model of the building was drawn using grid lines as per Beam Column layout. Member property were assigned to different spans in accordance with their intended use and the specification in IS 456:2000. Concrete grade of M25 is used for all members with HYSD 415 steel reinforcement. The modeled RCC structure was found to be safe under all default load combinations of live load, dead load, wind load and earthquake load as per code during the design check.

Table -1: Member sections

NAME	DIMENSIONS
Beam	300mm x 400mm
Plinth beam	300mm x 400mm
Column	450mmx450mm
Footing column	450mm x 450mm
Panel	100 mm , M25
Slab	200 mm , M25

Blast load was applied as Pulse load using Time History functions of corresponding Peak reflected pressure for each panel. Duration of positive phase was input through value of t_A (arrival time), td (Rise time) and t_{of} or t_{rf} (End time) in milliseconds. The Time-History functions were connected to corresponding panel loads defined in KN/m² and assigned with respect to the face and panel location from point of detonation of Blast on ground.

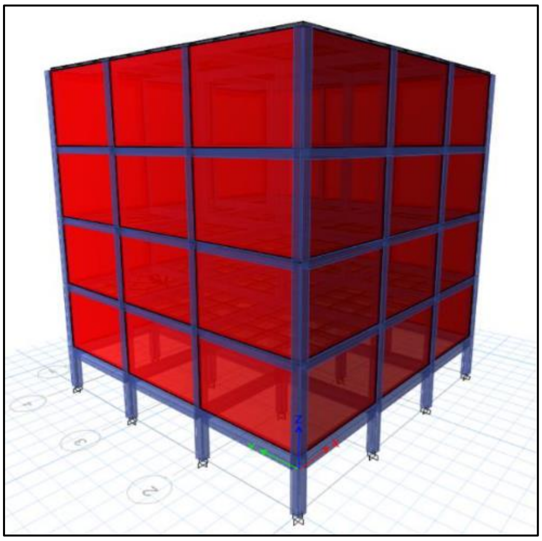

Fig-3: 3D view of the structure

4. RESULTS AND DISCUSSIONS

It was observed that the failure of the structure is due to the localized failure of the building and the details of the failed beams and columns are given below:

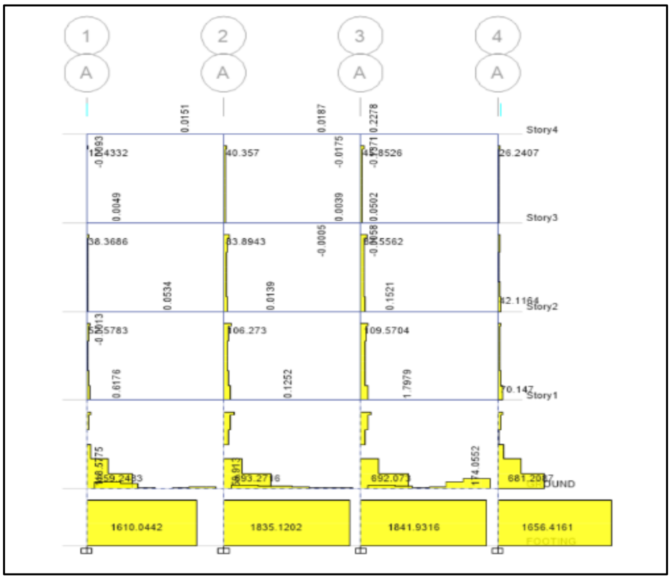

Fig-4: SFD of the structure when subjected to blast loading

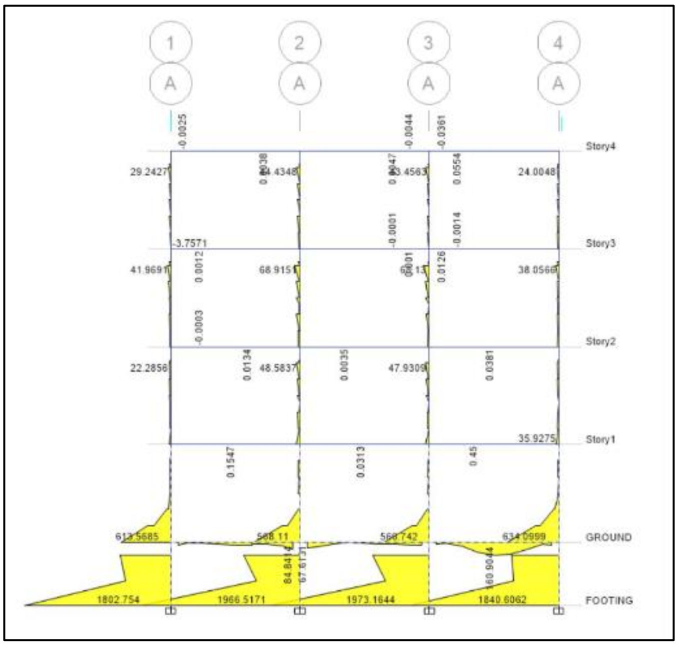

Fig-5: BMD of the structure when subjected to blast loading

4.1 Recommendations for planning blast resistant building

Some possible methods that can be employed to enhance blast resistance of a structure are:

- Use of Laced Steel Concrete Composites (LSCC)- LSCC developed by CSI-SERC, Chennai uses innovative integration of structural elements to increase structural integrity. In LSCC regular reinforcement bars are replaced by perforated steel plates connected by steel reinforcement rods and cross rods beside conventional concrete.
- Slurry Infiltrated Fibre Reinforced Concrete (SIFCON) -Displacement of a structure subjected to blast load reduced to about 25% to 30% when RCC was substituted by SIFCON.
- Constrution of Blast wall outside the building
- Avoid slender projections and long corridors
- Prefer a building with regular geometry
- Appendix C of IS4991- also gives general guidelines to be followed for a blast resistant building.

5. CONCLUSIONS

The study of blast resistant design refers to improving structural integrity of structures instead of complete collapse of building. The present study on G+3 RCC building which was affected by a surface blast of 3300 lbs from a standoff of 20m and the subsequent general failure was studied. The impact of blast led to the failure of 40 structural elements, from the failure pattern it has been observed that surface blast impact more predominantly the foundation and subsequent upper stories and not the entire building. This validated the blast characteristics of incurring localized failure. Facing columns and beams along with parallel faces were the ones to be greatly impacted and a twisting deformation happened to the building.

Technical information in form of formula, graph and diagrams about blast have been collected, adapted and presented in this study for calculation of external explosion load to be considered in the blast protection design of a structure. Method of blast load prediction recommended by UFC 3-340-02 2008 was used for the determination of blast loads over the method prescribed by IS 4491-1968 due to the prevailing inaccuracy and confusion in the latter method that led to uneconomic design. Thus in depth method to quantify the blast load affecting a building has been discussed and a method to apply this dynamic load on a structure in ETABS has also been recommended in this study.

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