# Nonlinear Analysis of a Multiple Story Building Under Uniform Blast Loading

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**Abstract-** The design of structures to critical can be heavily modified by explosions or shocks effects; in reality, intentional disruptions, blasts, or impacts have unfortunately become part of the possible load scenarios that could act on construction structures during their lifetime. The use of vehicle bombs to attack city centers or bombs intentionally put on construction facilities has been a feature of campaigns by terrorist organizations around the world. A bomb explosion within or immediately nearby a building can cause catastrophic damage on the building's external and internal structural frames, collapsing of walls, blowing out of large expanses of windows, and shutting down of critical life-safety systems. Loss of life and injuries to occupants can result from many causes, including direct blast-effects, structural collapse, debris impact, fire, and smoke. The response of reinforced concrete structures subjected to blast loads can be studied numerically using commercial finite element programs. This paper, hence, to get the structural response of structural elements within a 6 storeys building, which is composed a concrete frame a simulation using the finite element programs ABAQUS.

**Keywords:** Blast, load, structure, finite element, building.

## 1. Introduction

A number of analytical and numerical models have been published in the international literature using software's for Scientifics and engineering designs. Blast loads have received more attention in recent years because of accidental or intentional events (terrorist attacks) affected important structures. Traditionally, little research on the blast resistance of structures has appeared in the open literature. Enrin et al. [1] and Ishikawa et al. [2] , Studied the performance of prestressed concrete beams when subjected to impact loading, bounded and unbounded prestressed beams were tested experimentally and analytically. It was found that, while static loading resulted in failure of the compression concrete for both the bonded and unbounded specimens, the higher load rate induced by impact resulted in the breaking of the prestressed tendon. Compared to prestressed concrete, reinforced concrete has received much more attention from researchers over the years. Magnusson and Hallgren [3], in their study revealed that concrete beams show an increased load capacity for blast loading relative to static loading. Luccioni and Luege [4], by analysing the behaviour of concrete pavements subjected to blast loads produced by the detonation of high explosives, performed the tests to assess the concrete pavement slab under blast loads, as a result, the maximum vertical displacement obtained with the finite element model was significantly lower than the one measured experimentally for the third explosion using a 12.5 kg charge.

However, due to the high cost, it is almost impossible to investigate the response of the multi- storey buildings against blast loads with full-scale experimental tests. The analysis and design of structures subjected to blast loads require a detailed understanding of blast phenomena and the dynamic response of various structural elements. Luccioni, Ambrosini and Danesi [5], performed a detailed analysis of the structural failure of a reinforced concrete building caused by a blast load. However, most of the current numerical modeling research is involved with massive computational time and the model is difficult to build due to its complexity. Therefore, for designers, it is imperative to establish a simple modeling method to study the detailed behavior of the building after the blast denotation. Techniques developed by Feng Fu [6], with ABAQUS, a 3-D finite element model representing a 20-storey building was built to perform the blast analysis, a simplified direct simulation method of blast load is applied, the nonlinear material behavior and dynamic effects are also included in the simulation.

The collapse of a tall building under blast loading can also affect the adjacent buildings. Alex et al. [7], provided an accurate prediction of the effects of adjacent structures on the blast loads on a building in urban terrain. In the paper, a tentative attempt has been made to characterize the blast environment by considering a simple urban configuration with a relatively long, straight street segment and a T-junction at the far end. Numerical simulations using a computational Fluid dynamics (CFD) code Air3D has been used to determine the blast effects on building in a typical urban terrain. Each simulation provided the variation with distance of peak overpressure and impulse. When compared with the corresponding variations for a surface burst of a hemispherical charge in a free-field environment, these variations in the calculation of the pressure and impulse enhancement factors at each scaled distance from the charge. The resulting enhancement factors effectively modify the blast parameters obtained from simplified analytical techniques.

Blast load parameters are reasonably easily determined for rectangular columns and can be derived from either the literature or numerous utility programs. Qasrawi et al. [8], investigated the pressure distribution around a circular column constructed in AUTODYN a numerical model. The model was verified and showed good agreement with established values.

It was fund that the column radius increased the maximum reflected pressure at the point closest to the blast approached a maximum of approximately 0.9 of the design value quickly. It was also found that the pressure varied sinusoidal from this maximum to a minimum at the side of the column approximately equal to the incident pressure. The used a sinusoidal function to fit the distribution around the column with good results and this curve fit can be used to find an equivalent design value. A 3-D dynamic analysis of an entire structure is used to determine the effects of an explosion and the response of the structure. D. Makavicka [9], discussed about the methodology for dynamic response assessment and its application to the new RC building. The authors used a specific building as an example to illustrate the problem of an explosion and the threat to the safety of the structure due to the explosion of a rather large terrorist charge installed in a car and initiated on a road adjacent to the building. The structure response was assessed on the basis of the results of 3D dynamic calculation using the magnitudes of the internal forces and deflections and rotation of the central line of beam or plate sections of the structure. Evaluating a structure on the basis of the rotation of its sections is a methodology under development at present, and is in accordance with recent research trends. The authors have used limit rotation values (failure angle) determined experimentally on the basis of the explosion load of masonry, reinforced concrete and window glass plates, comparing their own results with results published by other authors.

## 2. Blast Loading

An explosion is a rapid release of stored energy characterized by a bright flash and an audible blast. Part of the energy is released as thermal radiation (flash); and part is coupled into the air as air blast and into the soil (ground) as ground shock, both as radials expanding shock waves. The rapid expansion of hot gases resulting from the detonation of an explosive charge gives rise to a compression wave called a shock wave, which propagates through the air. The blast wave instantaneously increases to a value of pressure above the ambient atmospheric pressure. This is referred to as the positive phase that decays as the shock wave expands outward from the explosion source. After a short time, the pressure behind the front may drop below the ambient pressure, Fig.1. During such a negative phase, a partial vacuum is created and air is sucked in. This is also accompanied by high suction winds that carry the debris for long distances away from the explosion source.

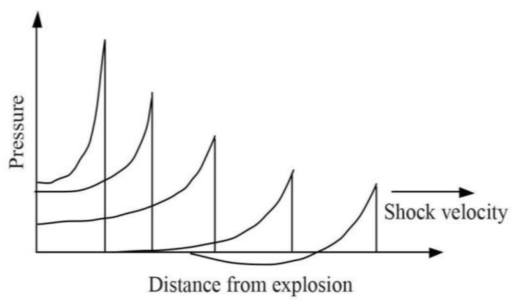



**Fig. 1.** Blast wave propagation (Abaqus 6.10)

As the shock wave travels outward from the charge, the pressure in the front of the wave, called the peak pressure, steadily decreases as shown in Fig. 2. At great distances from the charge, the peak pressure is infinitesimal, and the wave can be treated as a sound wave. The observed characteristics of air blast waves are found to be affected by the physical properties of the explosion source. At the arrival time $t_A$, following the explosion, pressure at that position suddenly increases to a peak value of overpressure, $P_{so}$, over the ambient pressure, $P_o$. The pressure then decays to ambient level at time td, then decays further to an under pressure $P_{so}^-$ (creating a partial vacuum) before eventually returning to ambient conditions at time $t_d + t_d^-$. The quantity $P_{so}$ is usually referred to as the peak side-on overpressure, incident peak overpressure or merely peak overpressure, TM 5-1300 [10].

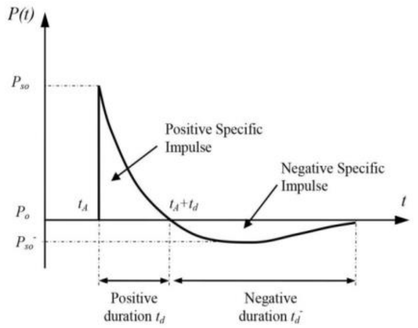



**Fig. 2.** Blast wave pressure – Time history (Abaqus 6.10)

*2.1. Blast Wave Scaling Laws*

All blast parameters are primarily dependent on the amount of energy released by a detonation in the form of a blast wave and the distance from the explosion. A universal normalized description of the blast effects can be given by scaling distance relative to (E/Po)1/3 and scaling pressure relative to Po, where E is the energy release (kJ) and Po the ambient pressure (typically 100 kN/m2). For convenience, however, it is general practice to express the basic explosive input or charge weight W, as an equivalent mass of TNT. Results are then given as a function of the dimensional distance parameter (scaled distance) $Z = R/W^{1/3}$, where R is the actual effective distance from the explosion. *W* is generally expressed in kilograms. Scaling laws provide parametric correlations between a particular explosion and a standard charge of the same substance.

*2.2. Prediction of Blast Pressure*

Blast wave parameters for conventional high explosive materials have been the focus of a number of studies during the 1950's and 1960's. Estimations of peak overpressure due to spherical blast based on scaled distance $Z = R/W^{1/3}$ was introduced by Brode (1955) as:

$$P_{S0} = \frac{6.7}{Z^3} + 1bar\left(P_{S0}\right) \quad (1)$$

$$P_{SO} = \frac{0.975}{Z} + \frac{1.455}{Z^2} + \frac{5.85}{Z^3} - 0.019 \;\; bar \quad (2)$$

$$(0.1 < P_{SO} < 10bar)$$

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

$$P_{SO} = 6784\frac{W}{R^3} + 93(\frac{W}{R^3})^{1/2} \quad (3)$$

Another expression of the peak overpressure in kPa is introduced by Mills (1987), in which *W* is expressed as the equivalent charge weight in kilograms of TNT and Z is the scaled distance, as follow:

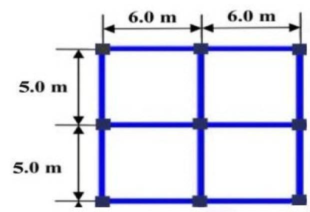
$$P_{SO} = \frac{1772}{Z^3} - \frac{114}{Z^2} + \frac{108}{Z} \quad (4)$$

In this paper the author used Mills formula shown in the Eq. 4, to calculate the peak overpressure. So the value of pressure calculated for 1m and 2m of stand points are respectively $P_{SO}$ = 1.766MPa and $P_{SO}$ = 0.25MPa.

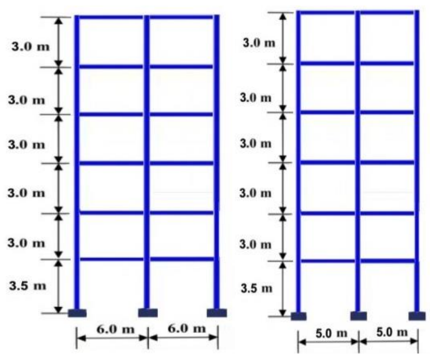
## 3. MODELLING

*3.1. Numerical Analyze*

The structure selected for this study is a 6-storey reinforced concrete building at the height of 18.5m. The length arranged as 6m in the longitudinal direction, and 6m span in the transverse direction. The storey height is 3.5 m for the first storey and a standard storey beyond the first storey is 3.0m. The plan view and structural configuration of the building are shown in Fig.3.The structural system of the building was made up of R.C Frames and Infill frames. The typical beam size used is 350x250mm; the size of the columns is 300 x 300 mm. The rebar used for the concrete beam section are 2ϕ16 and 2ϕ14 and for the column are 4ϕ16.Columns are spaced at 5 m in X direction and 6m in Y direction and are connected with beams and thickness of the slabs is 175mm. Computer Modeling of the building was performed using the finite element software ABAQUS. The 6 storey reinforced concrete building were frame structure of columns, beams, and slabs. The columns and beams were modeled as frame elements while the slabs were modeled as plate elements. The building model was assigned fixed bottom Support condition while a rigid diaphragm constraint was allotted to all floors.




View plan




Front and side elevation

**Fig. 3.** 6-storey building model

*3.2. Analytical model*

In this paper, finite element analysis is performed using the general purpose finite element package ABAQUS /Explicit version 6.10 ABAQUS /Explicit solves dynamic response problems using an explicit direct-integration procedure. In an implicit dynamic analysis, the integration operator matrix must be inverted and a set of nonlinear equilibrium equations must be solved at each time increment. In an explicit dynamic analysis displacements are calculated in terms of quantities that are known at the beginning of an increment; therefore, the global mass and stiffness matrices need not be formed, which means that each increment is relatively inexpensive compared to the increments in an implicit integration (Simulia, [11]). Therefore, explicit method is more efficient than the implicit integration method for solving extremely short-term events such as blast, explosion and impact.

Solid elements in 3D were used to model the deformable structure presented in this paper. In this case, C3D8R: 8-node linear brick, reduced integration, hourglass control, 3D Stress explicit was used to model frame Where the influence of mesh size has been studied and is sufficiently fine to ensure the accuracy of Models.

The general approach for solving the non-linear modal analysis, for most realistic results a very small time step is required to obtain a stable solution. In this paper a time step of 0.05ms has been used to make the simulation. The building is designed to resist lateral loads due to wind and seismic ground motion specified by Turkish Regulations on Building. The Fig.4 shows the attack phenome at the structural configuration of the blast attack.

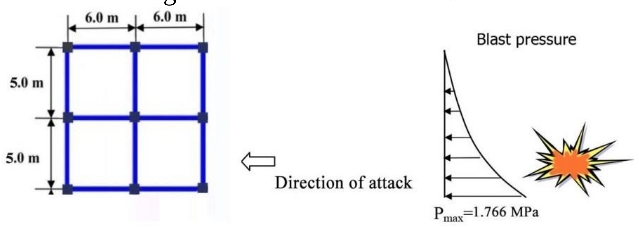



**Fig.4.** Structural configuration

## 4. Material Property

### *a) Concrete*

There are several models available for modelling the adhesive based on different criteria for plastic deformation of concrete. Predictions of joint performance at large strains close to joint failure depend on the model used. For the prediction of failure, stress and strain distributions in the adhesive need to be accurately calculated and a failure criterion for the adhesive needs to be established.

In this studies Drucker Prager has been used which is defining as follow:

The Drucker–Prager yield criterion (DP) is a pressure-dependent model for determining whether a material has failed or undergone plastic yielding. The yielding surface of the DP criterion may be considered depending on the internal friction angle of the material and its cohesion. In the space defined by the principal stresses, it is expressed as:

$$-\frac{2.sen\phi}{(3-sen\phi)}.I_1+\sqrt{1/2\left[(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_3)^2+(\sigma_2-\sigma_3)^2\right]}-\frac{6.c.\cos\phi}{(3-sen\phi)}=0 \quad (5)$$

Where, I1 = σ1 + σ2 + σ3, c= cohesion, ϕ = internal friction angle.

With the purpose of obtaining the classical representation, this yielding surface can be expressed in the following way:

$$(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_3)^2+(\sigma_2-\sigma_3)^2-A^2(I_1+B)^2=0 \quad (6)$$

Where:

$A=\frac{2\sqrt{2}sen\phi}{3-sen\phi}$, $B=\frac{3c\cos\phi}{sen\phi}$ and compression stresses are considered positives in the main stress space.

Fig.5 represents the classical quadric surface for a conventional concrete ($f_c$=25 MPa) with c =4.47 MPa, $\phi$ = 30º. The axis of the cone takes the direction of the vector (1, 1, 1).

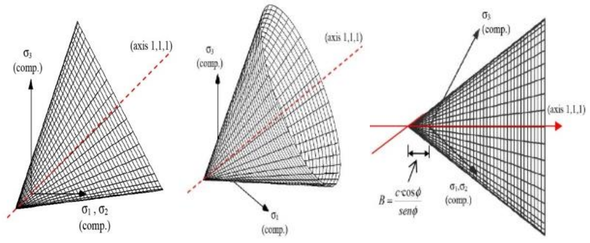



**Fig. 5.** Graphic representation of the DP criterion

The properties used for the concrete are as shown in the Table 1.

**Table 1.** Reinforced concrete mechanical properties

| Density (kg/m3) | Elastic modulus (MPa) | Poisson's ratio | Compression Strength (MPa) | Tension Strength (MPa) |
|---|---|---|---|---|
| 2400 | 2.6000 | 0.20 | 25 | 4 |

### *b) Steel*

The properties used for the steel are as shown in the Table 2.

**Table 2.** Reinforcement steel mechanical properties

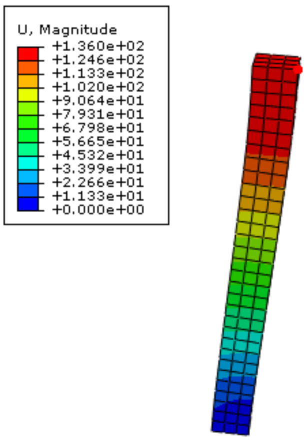
| Density (kg/m3) | Elastic | | Plastic | |
|---|---|---|---|---|
| | Young's modulus (MPa) | Poisson's ratio | Yield Stress (MPa) | Plastic Strain (MPa) |
| 7.85E-009 | 210.000 | 0.30 | 350 | 0 |

## 5. Results and discussions

In this study the attack has been occurred outside of the structure so the type of the explosion is classified as the open air explosion, Tehnički vjesnik (2012), which causes a wave that spreads from the source of detonation to the structure without any wave amplification. Due to the blast source's distance and height is away from the structure, the explosion provoked a wave increase due to the reflection of the ground before it contacts the structure. Also the explosion occurred on the ground and the initial pressure is immediately increased as a result of refraction on the ground.

Due to the evolving of high nonlinear behavior and the complexity of the model, to analyses the effect of blast loading, the column located on the left side of the attack at the ground floor has been selected. The Fig.6 illustrated the blast loading after the explosion and selected column deflection.


a) 3D model after the attack




b) A column displacement expressed in mm

**Fig. 6.** 6- Storey building modelled in ABAQUS

The analysis has done according to the peak pressure and standpoint calculated above. For each peak pressure and stand point the model has been simulated. It can be seen in the Fig.7 that there is a significant difference between two graphics in which the maximum value of displacement in the nodal shown above in the Fig. 6 (b) is: 0.136m for the case $P_{OS}$ =1.766MPa (standoff distance of 1m) and 0.037 for the case $P_{OS}$=0.25Mpa (2m).

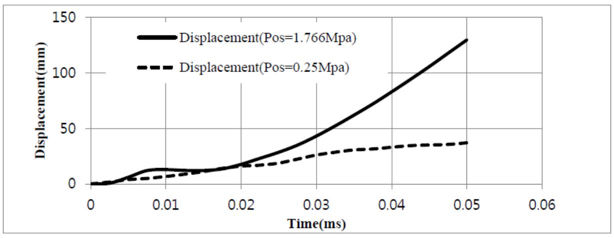



**Fig. 7.** Nodal displacement curve

After 0.125 ms the strain energy reached the maximum value of 0.146 MPa, in the case: $P_{os}$=1.766MPa (standoff distance of 1m) and got decrease till the failure point as shown in the Fig.8 in color blue. Also the same observation has been made on second curve which also increased from 0.006 MPa at 0.025ms and remain virtually constant.

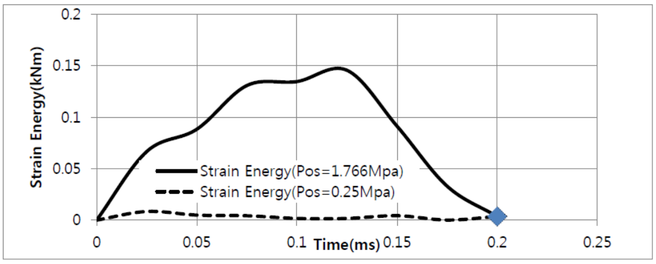



**Fig. 8.** Strain energy

The stress reach the peak value of 28, 9617 MPa at 0,01ms in the case: $P_{os}$=1.766MPa (standoff distance of 1m) and only at 0.015 reach the peak value of 25.7434 MPa in the second case as shown in the Fig. 9.

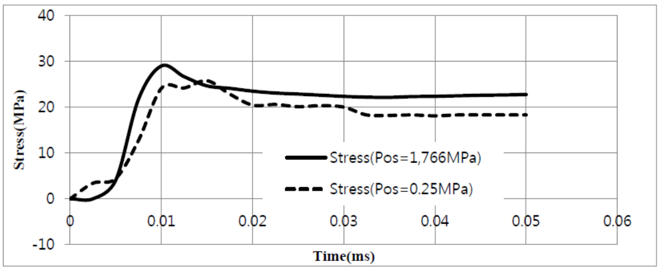



**Fig. 9.** Stress

The energy release after the explosion for the whole model reached the maximum value of 0. 4 E10 J, after 0.0085 ms as shown in the Fig.10, from zero and at the same moment started decaying till the end of the simulation.

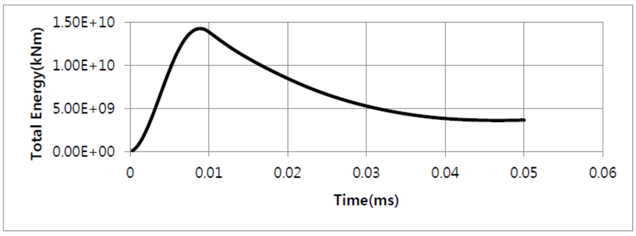



**Fig. 10.** Total energy.

## 6. Conclusion

According to the results the system affects significantly when the peak pressure (which is proportional to the charge weight) increases and standoff distance decreases respectively.

So the standoff distance is the key parameters that determines the blast pressure which decrease so far the effect of blast loading on the structure can be reduce by keeping or prevent the bomb attack as far away as possible by maximizing the standoff distance.

Blast has a characteristic of high amplitude, the results shows that columns subjected to high pressure they could cause big deformation and exceed the support reaction so the columns which are close to explosion are damaged and can be lost. Ones the critical load bearing columns lost which leads to sudden changes in the building geometry and load path which initiates a chain reaction of structural elements failure

The value of the strain energy is higher in the case of major peak pressure because of the higher lateral deflection presented, which shows better energy absorption.

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