Assessment of behavior of moment-resistant reinforced concrete buildings subjected to surface blast loads

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Abstract

In this study behavior of two reinforced concrete buildings which have been designed in accordance to national building codes, have been evaluated to surface blast loading. The two buildings are modeled in 3D dimensions in Abaqus/Explicit software. The buildings under investigation include 4-storey and 8-storey moment resistant frames. These two buildings are analyzed under surface blast loading and seismic loading. Then, structural responses such as base shear and base moment are compared with each other. Base on the responses, it is concluded that blast has much higher effects than earthquake on the buildings, although time period of blast is much less than of earthquake. Also the results show that if a seismic resistant building is to be designed under blast loads, it will be necessary to analyze and assess the building again to reach a safe level.

Keywords: surface blast loads, seismic loading, moment resistant building, base shear, base moment

1. INTRODUCTION

The blast phenomenon is a large scale, rapid and sudden release of energy, and can damage or destroy buildings. In recent years, blast loads have received more attention due to different accidental or intentional events related to important structures all over the world. Many researchs have been done on structural blast protection and the responses of buildings under explosive loads.

In order to achieve these objectives, the assessment of blast loads on structures is the prior stage. The accurate evaluation of the pressure distribution on frames is required for the analysis. Unlike other kinds of loads, blast wave propagates within a very short time and experiments have shown that the blast phenomenon is quite complex involving some important effects such as multiple blast wave reflections, the Mach effect and the negative phase of the blast wave.

Explosive materials can be classified according to their physical state as solids, liquids or gases. Solid explosives are mainly high explosives for which blast effects are best known. They can also be classified on the basis of their sensitivity to ignition as secondary or primary explosive. The latter is one that can be easily detonated by simple ignition from a spark, flame or impact. The detonation of a condensed high explosive generates hot gases under pressure up to 300 kilo bar and a temperature of about 3000-4000Cº. The hot gas expands forcing out the volume it occupies. As a consequence, a layer of compressed air (blast wave) forms in front of this gas volume containing most of the energy released by the explosion. Blast wave instantaneously increases to a value of pressure above the ambient atmospheric pressure. This is referred to as the side-on overpressure 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 (Figure 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.

2. DEFINITION OF THE PROBLEM

In order to examine the behavior of reinforced concrete buildings, two four storey and eight storey-reinforced concrete buildings performed by moment frame system in two directions have been designed accordance of the requirements of concrete and earthquake Iranian codes. These buildings have been modelled in 3D dimensions and have been designed by ETABS software. It is necessary to mention that these buildings are resilient and are located in the city of Mashhad in Iran. Also, the buildings have been designed under dead,

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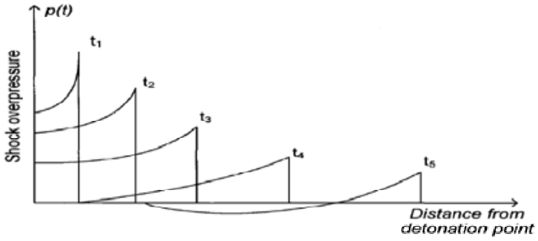


Figure 1. Blast wave propagation

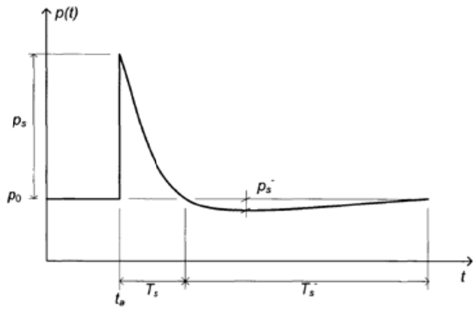


Figure 2. Blast wave pressure-Time history

live and earthquake loads. A symmetrical floor plan was selected to minimize torsion. The plan of buildings and location of explosive materials are shown in Figure 3. In this study, fifteen combinations of blast loadings are examined which are located in five points as shown in Figure 3. All the blast loadings have been done with 400,600 and 800kg TNT. The height of each storey is 3 meters. Also, $f_c = 35MPa$ and $f_y = 300MPa$.

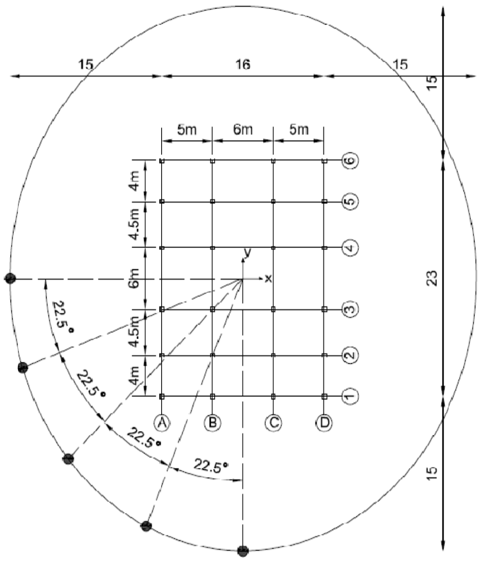
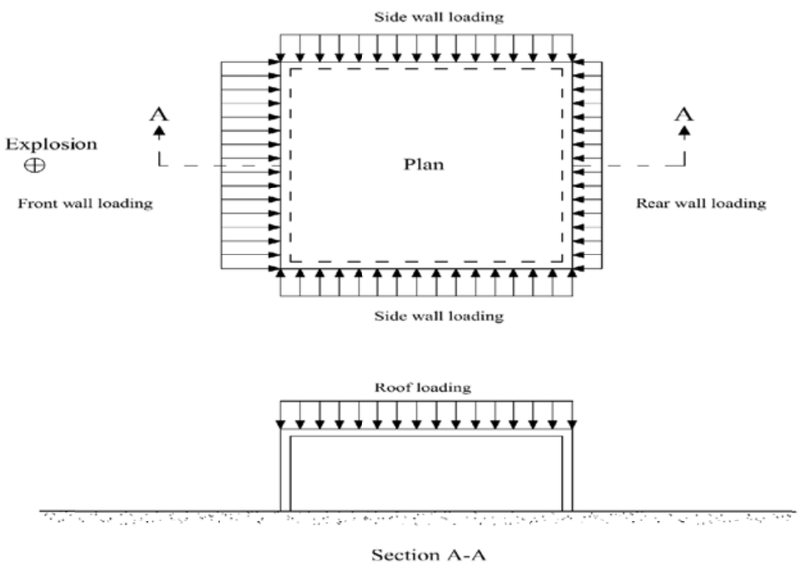


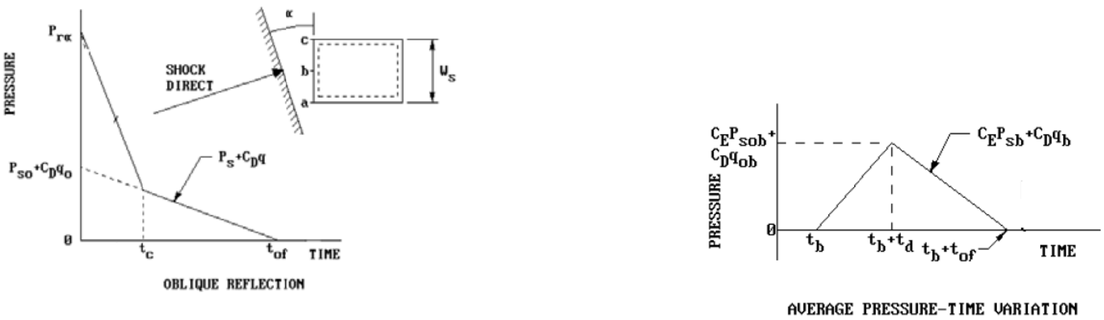
Figure 3. Location of explosives

3. MODELING OF BLAST LOADS

The interaction between reflected blast pressures and building structures is quite intricate. The blast waves caused pressure on the front, side and rear faces of buildings as well as on the roof. The reflected overpressure on the front face, where the angle of incidence is equal zero, is substantially higher than the overpressure on the rest of the building. In this study, loading has been done on the front walls, rear walls, side walls and roof. Therefore a simplified approach of considering the blast loads on the whole of buildings yields realistic results.

Blast loading has two phases: positive and negative phases. Generally, the exponentially decaying positive phase of the blast loading is approximate by triangle pulses whereas the negative phase is typically neglected. The blast loadings on the front, rear and side walls as well as roof of rectangular buildings are observed in Figure 4. It is necessary to mention that maximum and minimum pressure of blast is on front and rear wall respectively.





a.Front wall loading

b. Rear walls, side walls and roof loading

Figure 4. Blast loadings on a simply closed target

In this study, it is supposed that difference between front loading and rear loading is calculated on the faces of structure elements such as columns and beams. A separate curve is given for each blast parameter as a function of scaled distance $Z = \frac{R}{W^{1/3}}$, where R is the distance from the explosion and W is the mass of TNT. The explosion is assumed to occur at the ground level of building and blast loading has been supposed as a uniform loading because the center of height is considered in calculations of blast loading. The most important parameters of blast loading are P_r(peak reflected pressure), P_{so}(peak positive incident pressure), q(dynamic pressure) and i(impulse of incident). As a matter of fact, forces acting on the building associated with a plane shock wave are dependent upon both peak pressure and the impulse of the incident and dynamic pressures acting in the free-field. For each pressure range there is a particle or wind velocity associated with the blast wave that causes a dynamic pressure on objects in the path of the wave. In the free-field, these dynamic pressures are essentially functions of the air density and particle velocity. For typical conditions, standard relationships have been established between the peak incident pressure (P_{so}), the peak dynamic pressure (q_{ob}), the particle velocity and the air density behind the shock front. The magnitude of the dynamic pressures, particle velocity and air density is solely a function of the peak incident pressure and therefore, independent of the explosion size. Of three parameters, the dynamic pressure is the most important for determining loads on structures.

As it was said, in this paper, fifteen combinations of blast loadings are examined. In the process of blast loading, mass of TNT and angle between explosives and lengthy axe of the buildings are changing. All the blast loadings have been done with 400,600 and 800kg TNT.

3. MATERIAL MODELING

The concrete damage plasticity model is utilized to represent the compressive and tensile behavior of concrete. This model is a continuum, plasticity-based, damage model for concrete. It assumes that the main two failure mechanisms are tensile cracking and compressive crushing of concrete material. The evolution of the yield (or failure) surface is controlled by two hardening variables, $\tilde{\varepsilon}_t^{pl}$ and $\tilde{\varepsilon}_c^{pl}$ as tensile and compressive equivalent plastic strains, respectively. Also, the model assumes that uniaxial tensile and compressive response of concrete is characterized by damage plasticity, as shown in Figure 5. The damage variables (d) can take values from zero, respectively the undamaged material, to one, which represents total loss of strength.

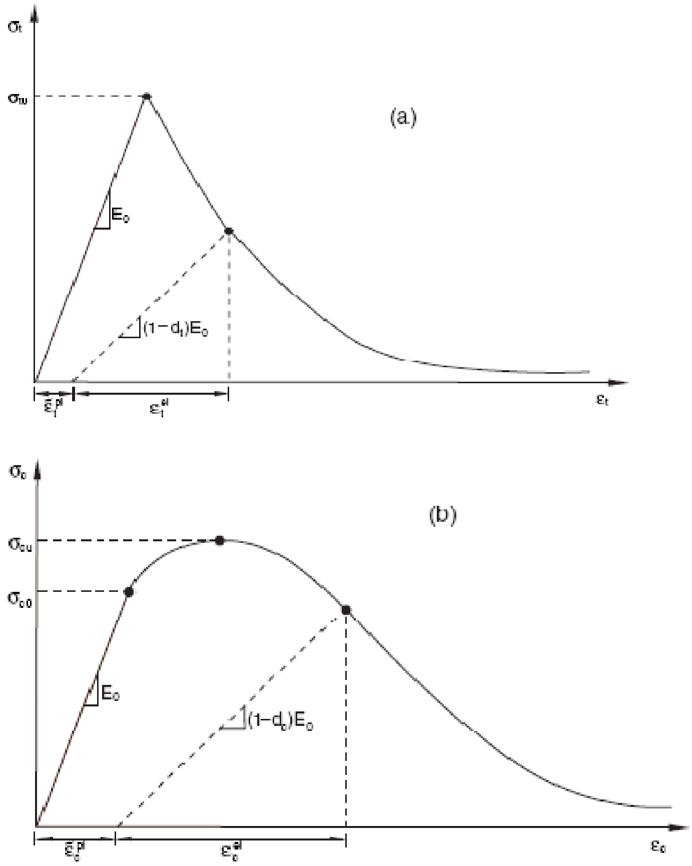


Figure 5. Response of concrete to uniaxial loading in tension (a) and compression (b)

In Abaqus software, reinforcement in concrete structures is typically provided by means of rebars, which are one-dimensional rods that can be defined singly or embedded in oriented surfaces. Rebars are typically used with metal plasticity models to describe the behaviour of the rebar material and are surpassed on a mesh of standard element types used to model concrete.

One of the most important points considered in the models is real behavior of concrete and steel in these models. As a matter of fact, in studies of blast effects, this fact that under extreme but short duration dynamic load effects such as blast which lasts only a fraction of second, any mechanism and element that dissipate energy and provides stiffness to the system should be considered. Several models can be found in the literature that are proposed for modeling high strain rate effects of concrete, both compressive and tensile strength. The CEB-FIP model code suggests a number of models for making strength of concrete at high strain rates. For compressive strength of concrete the CEB-FIP model code dynamic strength increase factor is given by:

$$\frac{f_{cd}}{f_c} = (\frac{\dot{\varepsilon}}{\dot{\varepsilon}_s})^{1.026\alpha} \quad for\ \dot{\varepsilon} \leq 30\ sec^{-1} \tag{1}$$

$$\frac{f_{cd}}{f_c} = \mu(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_s})^{1/3} \quad for\ \dot{\varepsilon} > 30\ sec^{-1} \tag{2}$$

$$log\mu = 6.156\alpha - 2 \tag{3}$$

$$\alpha = 1/(5+9f_c/f_{co}) \tag{4}$$

Where f_c is the static compressive strength of concrete; f_{cd} is the dynamic compressive strength; f_{co}=10MPa; $\dot{\varepsilon}$ is the strain rate in the range of 30×10^{-6} to $300s^{-1}$; $\dot{\varepsilon}_s$ is the static rate.

For tensile strength, the CEB-FIP model code provides the following equations for strain rates dependency.

$$\frac{f_{td}}{f_t} = (\frac{\dot{\varepsilon}}{\dot{\varepsilon}_s})^{1.016\delta} \quad for\ \dot{\varepsilon} \leq 30\ sec^{-1} \tag{5}$$

$$\frac{f_{td}}{f_t} = \beta(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_s})^{1/3} \quad for\ \dot{\varepsilon} > 30\ sec^{-1} \tag{6}$$

$$log\beta = 7.11\delta - 2.33 \tag{7}$$

$$\boldsymbol{\delta} = 1/(10+6f_c/f_{co}) \tag{8}$$

Where f_t is the static tensile strength of concrete; f_{td} is the dynamic tensile strength.

4. ANALYSIS OF THE STRUCTURES

In this study, the structures have been modeled in 3D dimensions by Abaqus software. The analysis of the structures is done by Abaqus/Explicit because, explicit dynamic analysis is computationally efficient for the analysis of large models with relatively short dynamic response times and uses a consistent, large deformation theory-models can undergo large rotations and large deformation.

The time devoted to the structures analysis is one second which is more than blast loading time period. By this method, behavior of the structures under blast loadings is assessed in free vibration phase. It is necessary to mention that the blast loadings are defined by mass of TNT and angle between explosives and lengthy axis of the structures. Also, number of buildings stories is introduced by f4 (4-storey) or f8 (8-storey). For example, 400y22.5f4 indicates that 400 kilogram TNT is located around the 4-storey building at angle of 22.5 degree between explosives and lengthy axis.

4. RESULTS

In this part, structural responses such as roof displacement and base shear of the buildings are assessed. With regard to 30 blast loadings which have been done, output data is a lot. So, in this paper, roof displacement and base shear of the buildings is shown in order to indicate behavior of the buildings under blast loading.

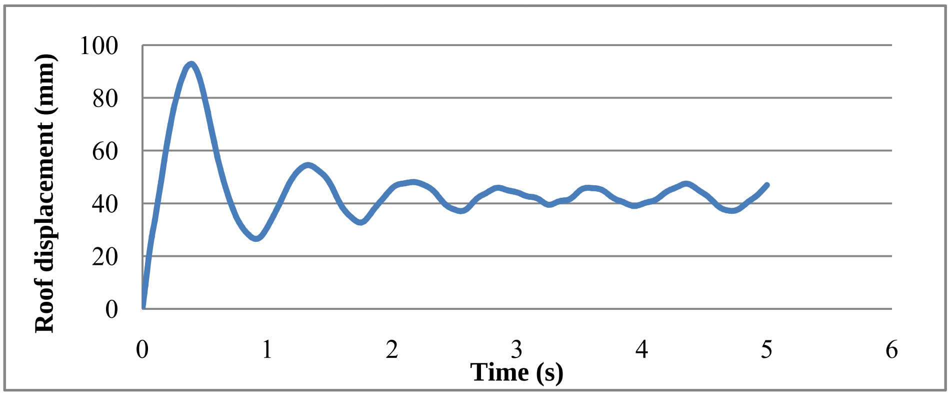


Figure 6. Roof displacement for 400y90f4 loading

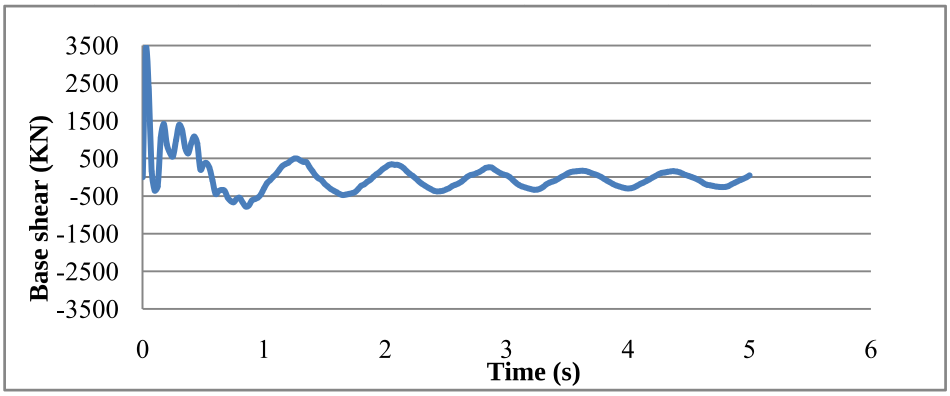


Figure 7. Base shear for 400y90f4 loading

Now, maximum roof drift ($\frac{roof\ displacement}{height\ of\ building}$) and base shear of the buildings are compared with each other.

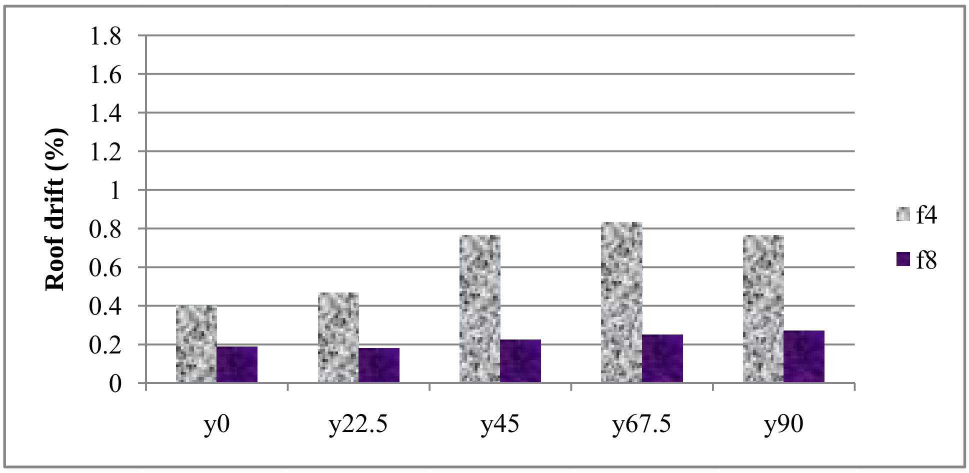


Figure 8. Maximum roof drift of the buildings to 400 kg TNT at the different angles

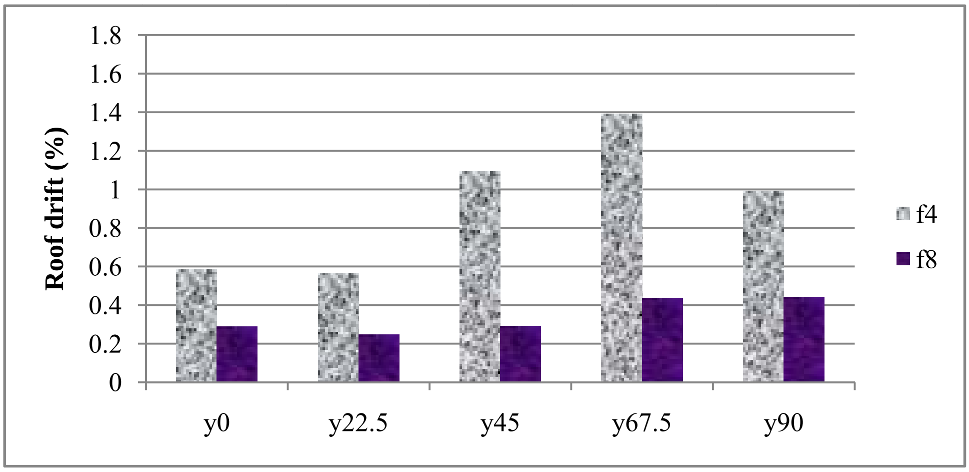


Figure 9. Maximum roof drift of the buildings to 600 kg TNT at the different angles

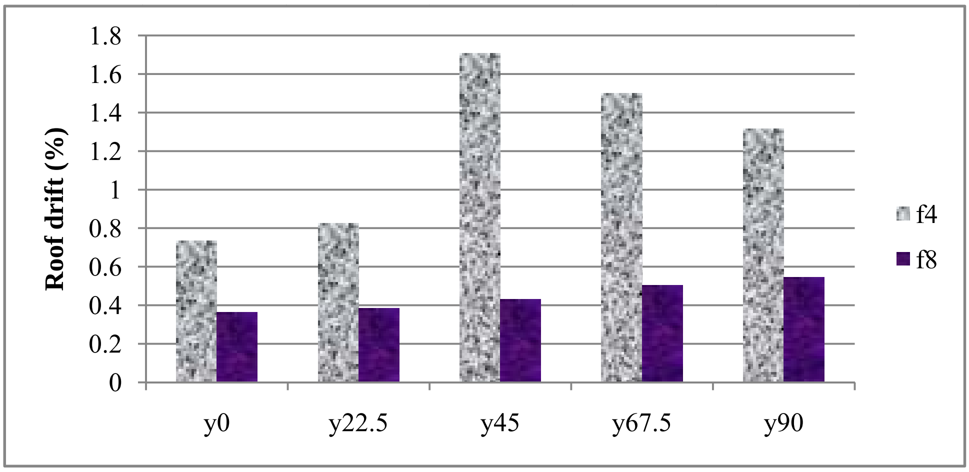


Figure 10. Maximum roof drift of the buildings to 800 kg TNT at the different angles

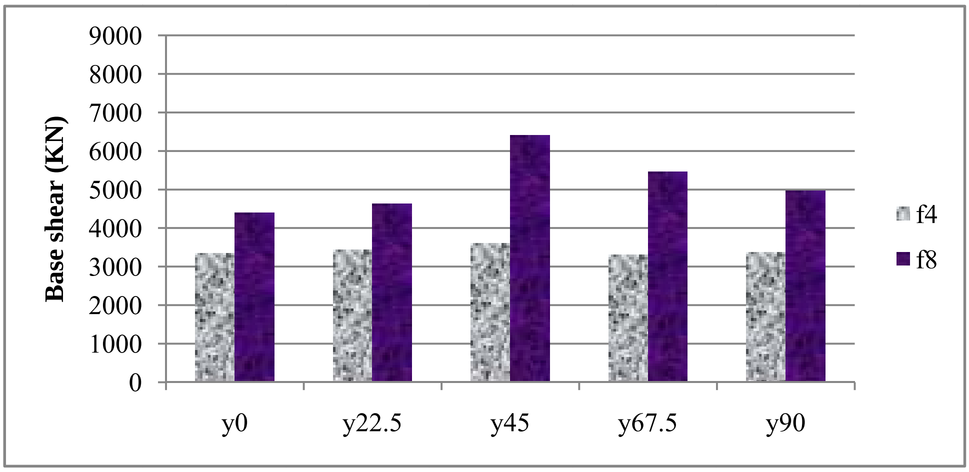


Figure 11. Maximum base shear of the buildings to 400 kg TNT at the different angles

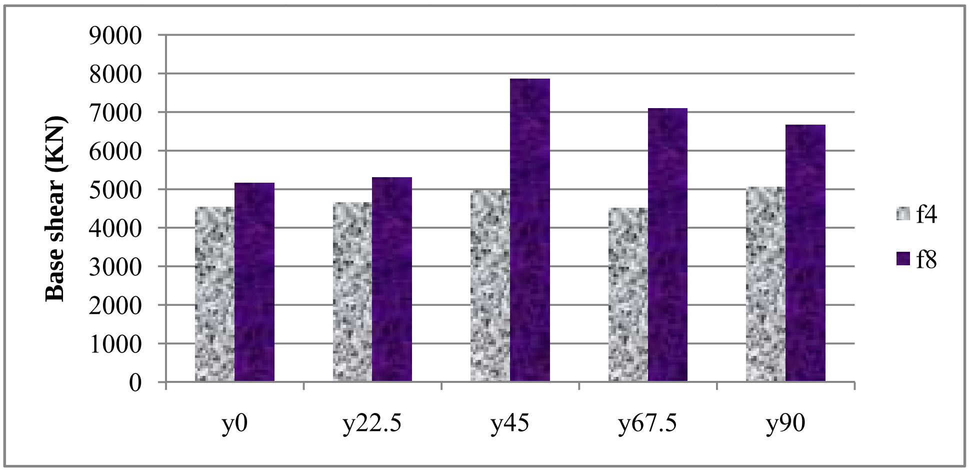


Figure 12. Maximum base shear of the buildings to 600 kg TNT at the different angles

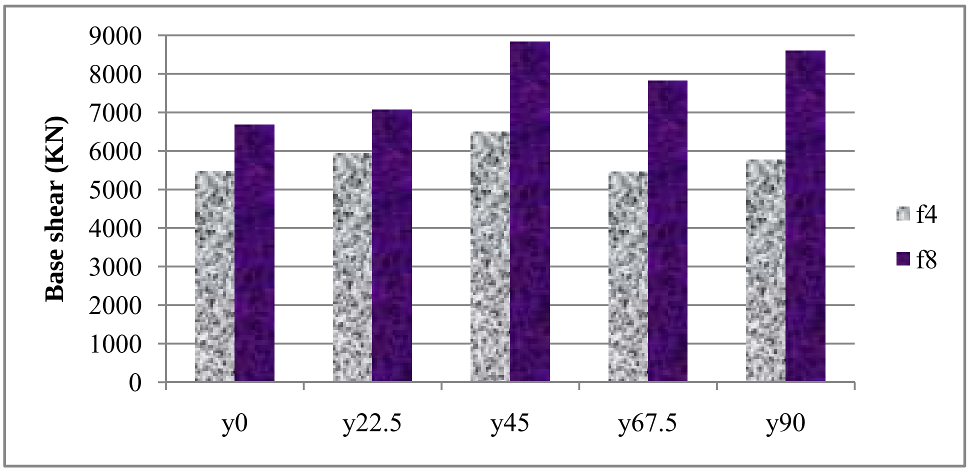


Figure 13. Maximum base shear of the buildings to 800 kg TNT at the different angles

5. CONCLUSIONS

Results show the 4-storey building has more critical behavior than the 8-storey building to blast. Also, results of blast analyses highlight that, the blast loadings have been entered to the 8-storey building at angles of 45, 67.5 and 90 degree produce more critical effects in the buildings than the blast loadings occurred at angles of 0 and 22.5 degree, because at angles of 45, 67.5 and 90 degree, front wall loading is on longitudinal wall while at angles of 0 and 22.5 degree front wall loading is on transverse wall. Also, the blast loadings occurred at angle of 45 degree produce approximately the most intense effects on the buildings.

6. REFERENCES

1. Abaqus.(2010), Abaqus/Standard User´s Manual, HKS,Inc.
2. ACI Committee 318.(2002), Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary(318R-02), American Concrete Institute, Farmington Hills, Mich, 443pp.
3. Collins, MP., and Mitchell, D.(1991) “Pre-stressed Concrete Structure.”, Prentic-Hall Inc, Englewood Cliffs, New Jersey, pp. 766.
4. Collins, MP., and Porsaz, A.(1989), ”Shear Design for High-Strength Concrete.”, CEB Bullentioned, Information, No. 193, pp. 77-83.
5. Etabs Nonlinear version 9.1.4.(2007), Computers and Structures Inc., Berkeley, CA.
6. Malvar, L. J., and Crawford, J. E.(1998), “Dynamic increase factors for concrete.” Proc., 28th DDESB Seminar, DDESB, Orlando, Fla.
7. Malvar, L.J., and Ross, C.A.,(1998), “Review of strain rate effects for concrete in tension.” Journal. ACI Mater, 95(6), pp. 735-739.
8. USDOD.(2008), Unified facilities criteria- Structures to resist the effects of accidental explosions, Document No. UFC 3-340-02, U.S. Department of Defence (USDOD), Washington D.C, USA.