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Assessment of existing structures under the action of gravity, earthquake and blast loads

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Abstract- ***Regarding to what was happening in the global world of terrorist attacks that often targeted to damage public institutions, communications towers, electrical towers, public facilities and historical places. It is now important to consider the blast loads in the design consideration and strengthening for any type of building, and adding this type of loading in the international design codes. Through this paper we will focus on the significant effect on existing structure will happen due to bomb with different weights of TNT and stand-off distances.***

Index Terms- **Blast, Time History, Displacement, Reinforced concrete**

I. INTRODUCTION

The terrorist attacks lead all over the world to be interested in studying the impact and blast loads, and search how it effect on the buildings stability and behavior. The explosion attacks are considering one of the impact load source, because the damage and collapse of a charge weight.

The velocity of the shocks governs the response of the structure. Low-velocity impacts may cause quasi-static response, while hyper-velocity shocks can cause the properties of the material change.

In other words, the dynamic response of structural components subjected to short duration impacts is difference from other type of loads, [3].

Blast load is a relatively large dynamic load applied to the whole or parts of the structure in a comparatively short time period. The explosion of bombs in and around buildings can cause catastrophic impacts on thestructural integrity of the building, such as damage to the external and internal structural frames and collapse ofwalls. Moreover, loss of life can result from the collapse of the structure. Understanding the performance of structural system under explosion is of great importance to provide buildings which eliminate orminimize damage to building and property in the event of explosion. The analysis and design of blast resistantstructures require a detailed understanding of explosives, blast phenomena and blast effects on buildings.

In this paper, the focus will be on the simplified method of blast load calculations, to evaluate the effect of blast loads on traditional building were designed to resist vertical and lateral loads, and did not consider any explosive loads.

I. EXPLOSIONS AND BLAST PHENOMENON

An explosion is defined as a large-scale, rapid and sudden release of energy. Explosions can be categorized on the basis of their nature as physical, nuclear, or chemical events. In physical explosions, energy may be released from the catastrophic failure of a cylinder of compressed gas, volcanic eruptions or even mixing of two liquids at different temperatures.

In nuclear explosion, energy is released from the formation of different atomic nuclei by the redistribution of the proton and neutrons within the interacting nuclei, whereas the rapid oxidation of fuel elements (carbon and hydrogen atoms) is the main source of energy in the case of chemical explosions [7].

Explosive material can be classified according to their physical state of 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. Materials such as mercury fulminate and lead azide are primary explosives. Secondary explosives when detonated create blast waves which can result in widespread damage to the surroundings.

The detonation of a condensed high explosive generate hot gases under pressure up to 300 kilo bar and a temperature of about 3000 – 4000 C^o . The hot gas expands forcing out the volume it occupies. As a

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consequence, a layer of compressed air 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, a pressure behind the front may drop below the ambient pressure (Figure 1).

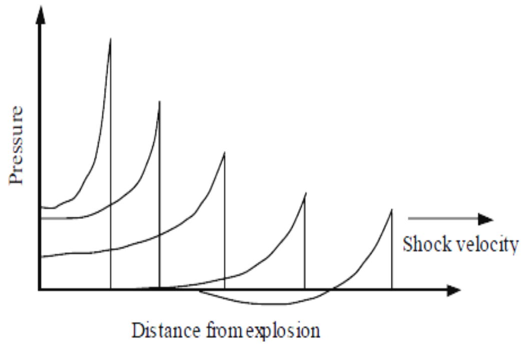

Fig 1: Blast wave propagation

II. EXPLOSIVE AIR BLAST LOADING

The threat of a conventional bomb is defined by two equally important elements, the bomb size, or charge weight *W*, and the stand-off distance *R*between the blast source and the target (Figure 2).

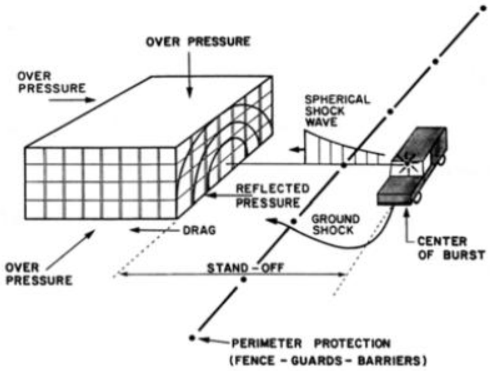

Fig 2: Blast loads on a building

For example, the blast occurred at the basement of World Trade Center in 1993 has the charge weight of 816.5 kg TNT. The Oklahoma bomb in 1995 has a charge weight of 1841 kg at a standoff distance 4.5m (Longinow, 1996).

The observed characteristics of air blast waves are found to be affected by the physical properties of the explosion source. (Figure 3) shows a typical blast pressure profile. At the arrival time t_A, following the explosion pressure at that position suddenly increases to a peak value of over pressure P_{so}, over the ambient pressure P_o. The pressure then decays to ambient level at time t_d, 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 (TM 5 – 1300, 1990) [1].

The incident peak over pressure P_{so} are amplified by a reflection factor as the shock wave encounters an object or structure in its path. Except for specific focusing of high intensity shock waves are near45^{o}incidence, these reflection factors are typically greatest for normal incidence (a surface adjacent and perpendicular to the source) and diminish with the angular position relative to the source. Reflection factors depend on the intensity of the shock wave, and for large explosives at normal incidence these reflection factors may enhance the incident

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pressure by as much as an order of magnitude. Throughout the pressure-time profile, two main phases can be observed; portion above ambient is called positive phase of duration t_d, while that below ambient is called negative phase of duration ,t_d^-.The negative phase is of longer duration and allow erintensity than the positive duration. As the stand-off distance increases, the duration of the positive-phase blast wave increases resulting in a lower-amplitude, longer-duration shock pulse. Charges situated extremely close to a target structure impose a highly impulsive, high intensity pressure load over a localized region of the structure; charges situated further away produce a lower-intensity, longer-duration uniform pressure distribution over the entire structure. Eventually, the entire structure is engulfed in this hock wave, with reflection and diffraction effect screating 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.

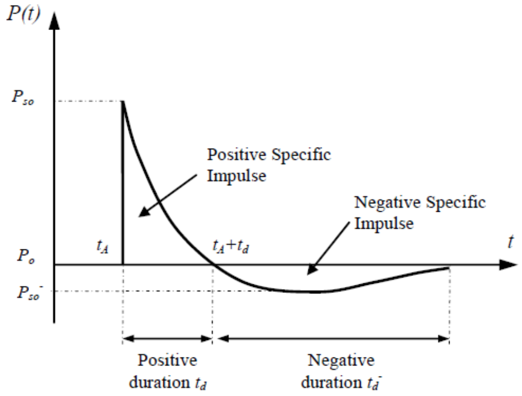

Fig 3: Blast wave pressure – Time history

III. STRUCTURAL ASPECT OF BLAST RESISTANT BUILDING DESIGN

The front face of a building experiences peak overpressures due to reflection of an external blast wave. Once the initial blast wave has passed the reflected surface of the building, the peak overpressure decays to zero. As the sides and the top faces of the building are exposed to overpressures (which has no reflections and are lower than the reflected overpressures on the front face), a relieving effect of blast overpressure is experienced on the front face. The rear of the structure experiences no pressure until the blast wave has traveled the length of the structure and a compression wave has begun to move towards the center of the rear face. Therefore the pressure built up is not instantaneous. On the other hand, there will be a time lag in the development of pressures and loads on the front and back faces. This time lag causes translational forces to act on the building in the direction of the blast wave (Figure 4)

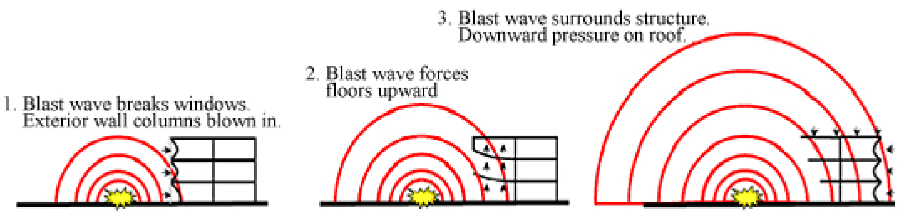

Fig 4: Sequence of air-blast effects

Blast loadings are extra ordinary load cases however, during structural design, this effect should be taken into account with other loads by an adequate ratio. Similar to the static loaded case design, blast resistant dynamic design also uses the limit state design techniques which are collapse limit design and functionality limit design. In collapse limit design the target is to provide enough ductility to the building so that the explosion energy is distributed to the structure without overall collapse. For collapse limit design the behavior of structural member connections is crucial. In the case of an explosion, significant translational movement and moment occur and the loads involved should be transferred from the beams to columns. The structure doesn't collapse after the explosion however it cannot function anymore.

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Functionality limit design however, requires the building to continue functionality after a possible explosion occurred. Only non-structural members like windows or cladding may need maintenance after an explosion so that they should be designed ductile enough, [1].

When the positive phase of the shock wave is shorter than the natural vibration period of the structure, the explosion effect vanishes before the structure responds. This kind of blast loading is defined as "impulsive loading". If the positive phase is longer than the natural vibration period of the structure, the load can be assumed constant when the structure has maximum deformation. This maximum deformation is a function of the blast loading and the structural rigidity. This kind of blast loading is defined as "quasi-static loading". Finally, if the positive phase duration is similar to the natural vibration period of the structure, the behavior of the structure becomes quite complicated. This case can be defined as "dynamic loading".

Frame buildings designed to resist gravity, wind loads and earthquake loads in the normal way have frequently been found to be deficient in two respects. When subjected to blast loading; the failure of beam-to-column connections and the inability of the structure to tolerate load reversal. Beam-to-column connections can be subjected to very high forces as the result of an explosion. These forces will have a horizontal component arising from the walls of the building and a vertical component from the differential loading on the upper and lower surfaces of floors. Providing additional robustness to these connections can be a significant enhancement.
Cast-in-situ reinforced concrete floor slabs are the preferred option for blast resistant buildings, but it may be necessary to consider the use of precast floors in some circumstances. Precast floor units are not recommended for use at first floor where the risk from an internal explosion is greatest. Lightweight roofs and more particularly, glass roofs should be avoided and a reinforced concrete or precast concrete slab is to be preferred, [4].

Structural design after an environmental and architectural blast resistant design, as well stands for a great importance to prevent the overall collapse of a building. With correct selection of the structural system, well designed beam-column connections, structural elements designed adequately, moment frames that transfer sufficient load and high quality material; it's possible to build a blast resistant building. Every single member should be designed to bear the possible blast loading. For the existing structures, retrofitting of the structural elements might be essential. Although these precautions will increase the cost of construction, to protect special buildings with terrorist attack risk like embassies, federal buildings or trade centers is unquestionable, [6].

IV. MODEL DEVELOPMENT

The structure selected for this study is an existing structure with bullet proof glass façade and it is consisting of5 stories reinforced concrete building standing at height of 24.425m. The center-to-center plan dimensions are 33.60m in both direction. The first story height is 4.00m, for typical floors the height is 3.85m and for the upper roof story the height is 2.775m. The floors layout and dimensions as shown in (Figure 5).

The structural system of the building was made of reinforced concrete frames. The common beam size used is 300X600mm; the columns size was varied from 300X550mm to 350X1100mm, and slabs thickness was varied from 150 mm to 180 mm. This building included one core connected with shear wall and another single shear wall with thickness 300 mm for each.

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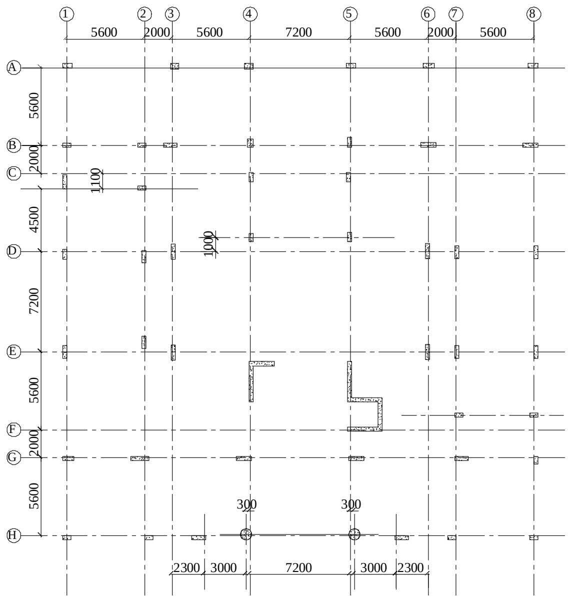

Fig 5-a: Columns and Axes

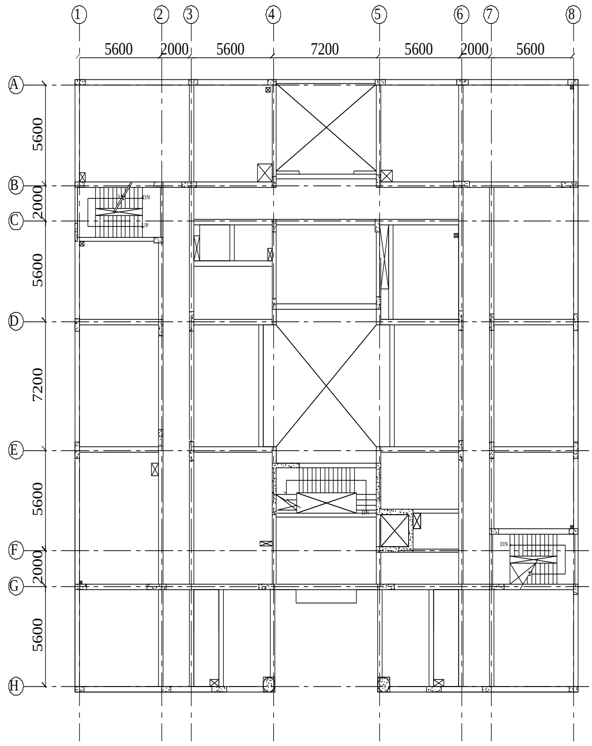

Fig 5-b: Typical Floor Layout

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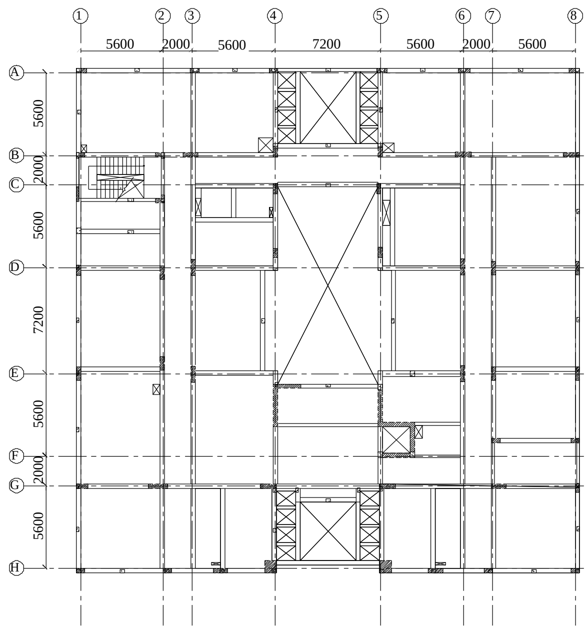

Fig 5-c: Roof Floor Layout

V. ANALYTICAL MODEL

A. Modeling of frame

The space frame building is modeled in ETABs 2013. The beams and columns are modeled as frame elements, the slab is modeled as a shell element, and cores are modeled as reinforced concrete wall elements. The bottom of frame is hinged. The diaphragm action is considered at every floor level. The beams and columns are properly connected using the end offset provisions. Figure 6 shows the 3D model of the frame building using ETABs.

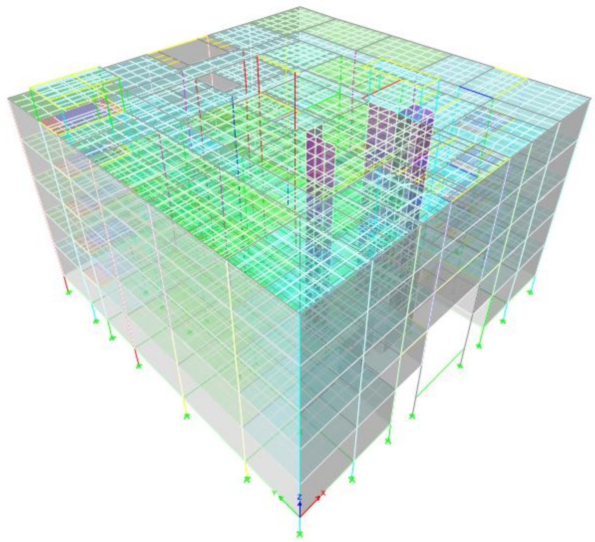

Fig 6: 3D Model for Frame Building by ETABS

B. Assigning Blast Load on Structure by ETABs

1- Define a static load case for blast load. Separate case for each direction.
2- Draw shells on the external surface of the building with Material of walls.

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ISO 9001:2008 Certified
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3- Assign uniform load on the external surface and the required direction.
4- Define time history function for each direction (Time-Value relation).
5- Define time history case for each direction, and add the related blast load and function.
6- Run modal analysis using Ritz vectors and considering the static blast loads.

After modal analysis, a short duration blast is applied to the frames and the displacements, and pressures response are studied, as per the equations and charts are represented in *"UFC 3 -340-02"*, [11].

Table (1) shows the maximum pressure applied on the bullet proof glass.

		W - Bomb Weight (Kg) TNT		
		500	3000	5000
R - Ground Distance (m)	10	595.852		
	20	56.667		
	30	16.24	105.461	171.268
	40	10.187	44.293	76.898
	50	6.721	24.941	42.184

Table 1: Maximum Pressure Applied on Bullet Proof Glass

C. Stories Displacement

The stories displacement will show only for listed cases mentioned in (Table 2).

Blast Load Case	Bomb Weight (Kg) TNT	Ground Distance (m)	Max. Displacement Time (ms)
1	500	10	3.44
2		20	11.82
3		30	17.96
4		40	18.46
5		50	25.06
6	3000	30	14.44
7		40	23.43
8		50	24.18
9	5000	30	16.19
10		40	21.19
11		50	31.22

Table 2: Selected Blast Load Cases

Also, in these curves the building stories are represented as numbers instead of labels as follow:

Base Elevation	=	0.000
Ground Elevation	=	2.100 m
First Elevation	=	6.250 m
Second Elevation	=	10.100 m
Third Elevation	=	13.950 m
Fourth Elevation	=	17.800 m
Roof Elevation	=	21.650 m
Upper Roof Elevation	=	24.425 m

The load cases which are selected in this study are Dead Load (D), Live Load (L), and Earthquake in more stiff direction for core and shear wall (Ex), and Blast Load (B).

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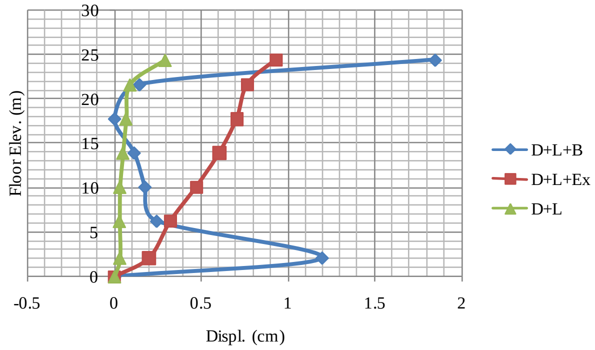

Fig 7: Case 1 (W= 500Kg, R= 10m)

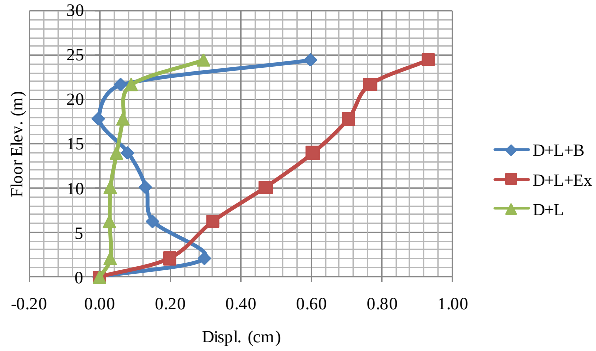

Fig 8: Case 2 (W= 500Kg. R= 20m)

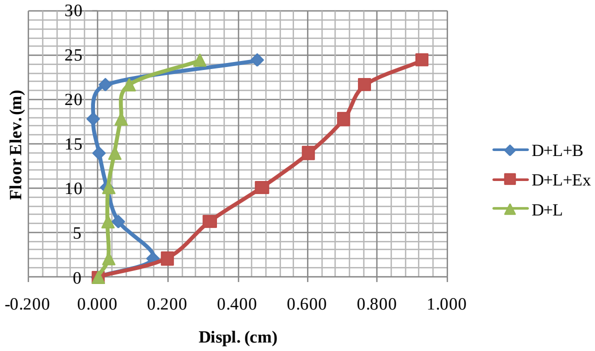

Fig 9: Case 3 (W= 500Kg, R= 30m)

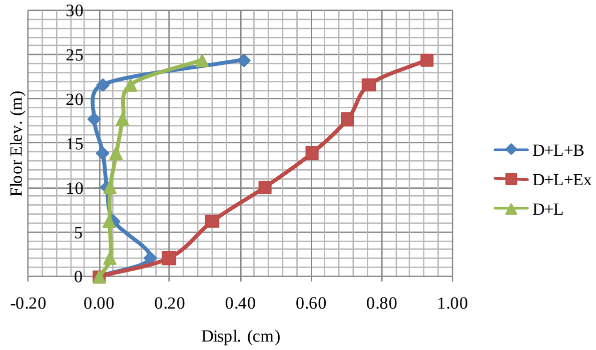

Fig 10: Case 4 (W= 500Kg, R= 40m)

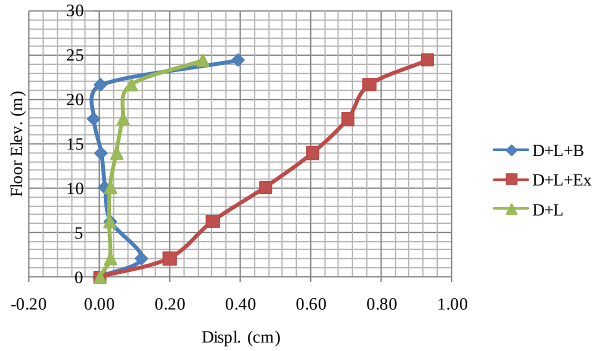

Fig 11: Case 5 (W= 500Kg, R= 50m)

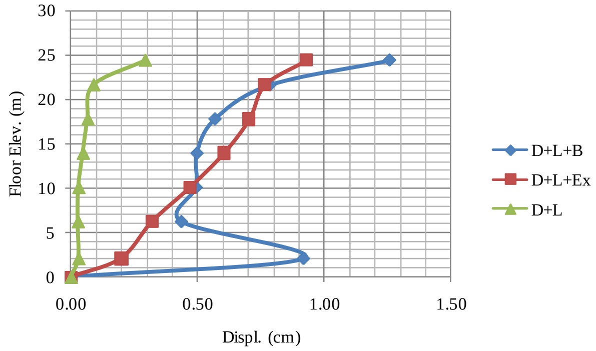

Fig 12: Case 6 (W= 3000Kg, R= 30m)

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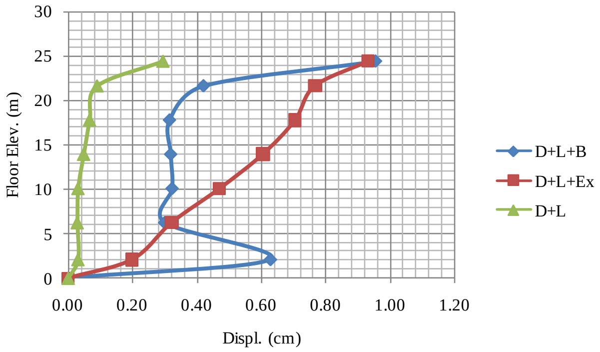

Fig 13: Case 7 (W= 3000Kg, R=40m)

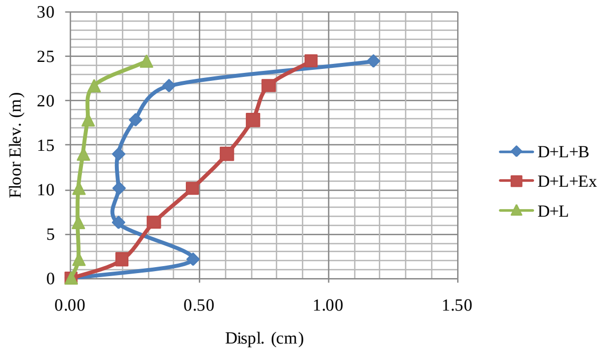

Fig 14: Case 8 (W= 3000Kg, R= 50m)

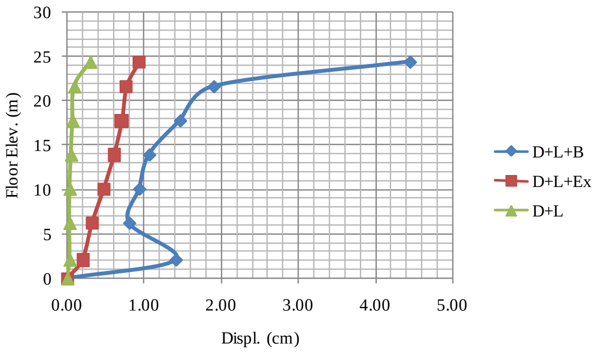

Fig 15: Case 9 (W=5000Kg, R= 30m)

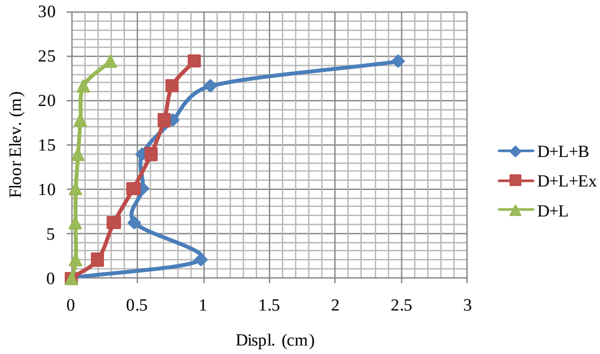

Fig 16: Case 10 (W=5000Kg, R= 40m)

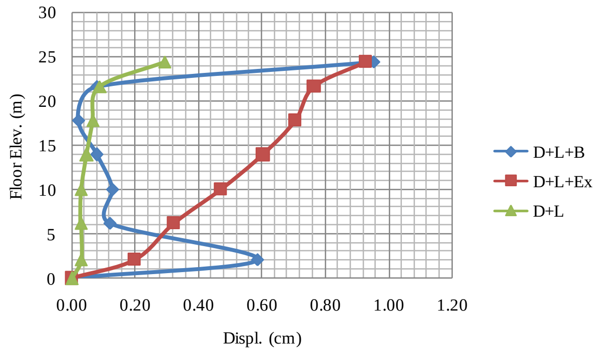

Fig 17: Case 11 (W=5000Kg, R= 50m)

VI. CONCLUSIONS

Based on the above results, the followingconclusion can be drawn as follows:

1. The significant effect on the building will happen when the charge weight (W) increases and the ground distance decreases.
2. The location, orientation and size of reinforced concrete cores and shear walls have a major effect on minimize blast pressure on building.
3. Depending only on framing system without any enhancement by using cores and / or shear walls will lead to major collapse, that can be shown in the weak stiffens direction for the mentioned building in this research.
4. The building was designed on the minimal earthquake parameters has the capability to resist the blast pressure by

using the special reinforcement details.

5. In this study it is found that the most optimum model is regular infill frame which shows the lowest value of story drift and the structure is very good in lateral stability against blast load. Therefore for economical design consideration the column size can reduce.
6. There is no significant effect on the upper floor because of low intensity of pressure on the upper floor due to increase of standoff distance from bottom floors to upper floors, therefore increase of standoff distance will reduce pressure on the upper floors.

VII. FUTURE ENHANCEMENT

1. Studying the effect of using Fiber Reinforced Concrete to minimize the floors displacement due to blast loads.
2. Studying to increase the reinforced shear walls in different location.

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COMPLIANCE WITH ETHICAL STANDARDS

This study is theoretical study and it is personal effort from the authors and no funding, and this paper will be a part of PhD thesis, which will be discussed in Cairo University – Faculty of Engineering.
Conflict of Interest: The authors declare that they have no conflict of interest.

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