

## **An Overview of International Standards Governing Blasting Operations**

**Hassan A. Mahmoud\*, Mohamed F. Abdallah**

Ph.D. Student, Civil Engineering Department, Alexandria University, Alexandria, Egypt  
Professor of Reinforced Concrete Structures, Civil Engineering Department, Alexandria University, Egypt

**KEYWORDS:** Egyptian Code, International Codes, Standards

### **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 design codes which are not covering this type of loading. Through this paper we present most of international codes are giving regulations and consideration regarding blast load, also we will show the suitable regulations can be used and applied in Egyptian Design Code for Reinforced Concrete.

### **INTRODUCTION**

In recent years, a number of tragic terrorist attacks, particularly, in the world, have resulted in a number of initiatives to study the resistance of structures to blast. In addition, a number of research projects have been undertaken or are underway to develop mechanisms and systems to reduce the hazard of such attacks. The main aim of these efforts is to protect the safety of the occupants of the building, the rescue workers and those who are around the building whom can be killed or injured by the collapse of the structure and the falling debris, by adding the required regulations in codes are not covering this type of load like "Egyptian Design Code For Reinforced Concrete". From structural engineering and construction point of view, of course, one can design a building that can withstand a terrorist bomb attack with minimal or no damage. This has been done for years and continues to be done for militarily sensitive and other critical buildings that are necessary to be functional and occupied even after a bomb attack on them. Of course, designing such a highly protected building requires a significant amount of funding as well as resources. In addition, to achieve the objective of the minimal damage, the designers may end up sacrificing the exterior aesthetics and in some cases the internal functionality of the building. Although in case of military installations, the high cost and bunker like appearance of a building can be justified, however, for civilian buildings, such high costs cannot be afforded and the loss of aesthetics may not always be acceptable. This was because of the assumption that civilian buildings had a very low probability to be a target of terrorist attack. But it is seen that, it is not the case by events of September 11, 2001 bombing of World Trade Center and by bombings of two synagogue, British Embassy and HSBC Bank in Turkey on October 2004, and what was happening and increasing in Egypt since three years ago.

In our current codes either no measures are included or no references to documents related to blast effect on structures are made, even in military specifications. But as Turkey is in one of the seismically most active regions of the world and seismic effect together with necessary precautions takes more and more attention day after day. Past studies indicate that seismic precautions taken for reinforced concrete frame structures can result in positive effect for the structures which are subjected to terrorist attack therefore, blast effect. Therefore, this study is an initial attempt to add or select the suitable blast regulations and calculation method to our code.

### **EXPLOSIONS AND BLAST PHENOMENON**

In order to understand the nature, physics of explosion and blast wave creation as well as reflection from that explosion in order to be clarified with the behavior of concrete structures subjected to severe loading. When the blast wave hits a concrete surface, a shock wave propagates through the concrete. There are two main theories to describe the response, the Eulerian and Lagrangian methods, which are further described when dealing with numerical analysis by Aytodyn-3D. When treating the shock wave with the Eulerian method, where a fixed reference in space is chosen and the motions are derived with respect to that region, the shock wave theory is based on the conservation of mass, momentum and energy. When treating the shock wave by the Lagrangian method, with moving reference, the stress wave theory is based on the classic wave equation of motion, where equilibrium and compatibility are considered. An explosion is characterized by a physical or a chemical change in the material, which happens under sudden change of stored potential energy into mechanical work, with creation

of a blast wave and a powerful sound; FortH1 (1987). The explosive material can react in two ways, as (a) deflagration or (b) detonation. For deflagration, the chemical change in the reaction zone occurs below the sonic speed through the explosive material. While for a detonation, the chemical change in the reaction zone occurs over the sonic speed through the explosive material. In military situations, detonations are most common; for example, if a TNT charge explodes, this means that it decays as a detonation. In present thesis, by explosion is meant a detonation unless stated otherwise.

### FREE AIR BLAST PHENOMENON

A shock wave resulting from an explosive detonation in free air is termed an air-blast shock wave, or simply a blast wave where no amplification of the initial shock wave occurs between the explosive source and the protective structure. In the case of an airburst the pressure wave moves away from the center of the explosion and the blast wave that hits the ground surface will be reflected Figure (2). The reflected wave will coalesce with the incident wave and a Mach front is created, as shown in Figure (1) the point where the three shock fronts will meet, the incident wave, reflected wave and the Mach front is termed the triple point, (TM5, 2008).

It will be clear from figures (2 and 3) that there are main parameters to be considered for design structures or assessment existing structures, some of these parameters are:

1. Structure height.
2. Ground distance between bomb and structures.
3. Blast air pressure which based on the bomb weigh.

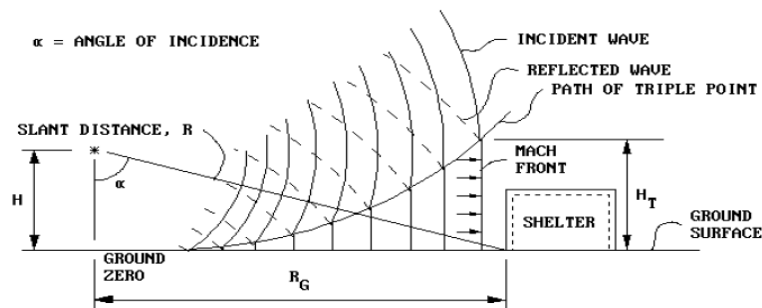


Fig. 1 Blast environment from an airburst, TM5 (2008)

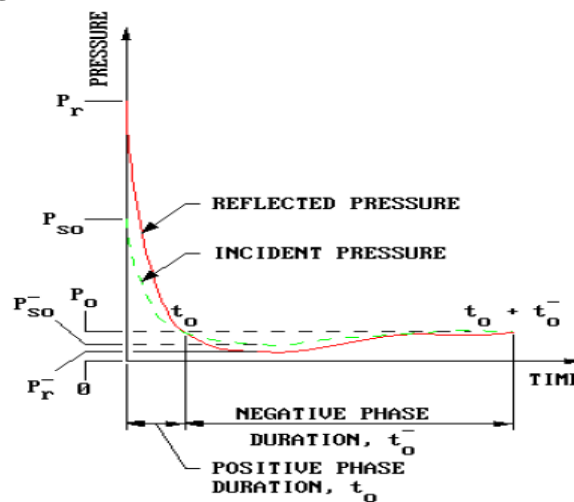


Fig. 2 Pressure-time variation for a free-air burst, TM5 (2008)

It is not possible to design structures for absolute safety, nor is it economical to design for abnormal events unless they have a reasonable chance of occurrence. Some of the incidents causing abnormal events might be: explosions due to gas, explosions of highly flammable liquids or bombs, vehicle impacts, foundation failures, failures resulting from construction and design errors. These events are not usually considered in the usual design process. On the other hand, events such as earthquakes, fires, high winds are part of building code requirements but they should not also cause progressive collapse.

It has become important to discuss this type of loads and add it to all the codes used in the design to protect or reduce the sudden structures collapse due to the explosion load.

## **CODES AND STANDARDS**

Since the progressive collapse of the Ronan Point apartment tower in 1968, British agencies established imperative requirements related with collapse prevention due to explosions. Successively many codes and standards have attempted to address the issue of this type of collapse. A small sampling of current and recent provisions related to progressive collapse will provide an indication of the alternative approaches being considered based on the research by Nair, 2003.

### **American Society of Civil Engineering (ASCE) 7-02**

Nair summarizes that The American Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures ASCE, 2002 has a section on “general structural integrity” states that: “Buildings and other structures shall be designed to sustain local damage with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage. It proposes achievement of this goal through an arrangement of the structural elements that provides stability to the entire structural system by transferring loads from any locally damaged region to adjacent regions capable of resisting those loads without collapse. Main emphasis is made over providing sufficient continuity, redundancy, or ductility, or a combination, in the members of the structure states Nair, 2003.”

The focus in the ASCE standard is mainly made on redundancy and alternate load paths over all other means of avoiding susceptibility to disproportionate collapse. But it is stated that the weak side of the code is that the degree of redundancy is not specified, and the requirements are entirely threat-independent.

### **American Concrete Institute (ACI) 318**

The American Concrete Institute Building Code Requirements for Structural Concrete (ACI, 2002) include extensive “Requirements for structural integrity” in the chapter on reinforcing steel details. Though the Commentary states that it “is the intent of this section to improve redundancy” there is no explicit mention of redundancy or alternate load paths in the Code. The Code provisions include a general statement that “In the detailing of reinforcement and connections, members of a structure shall be effectively tied together to improve integrity of the overall structure” and many specific prescriptive requirements for continuity of reinforcing steel and interconnection of components. There are additional requirements for the tying together of precast structural components. None of the ACI provisions are threat-specific in any way.

### **General Services Administrations (GSA) Progressive Collapse Guidelines 2003**

In June 2003, the United States General Services Administration (GSA) released their latest version for progressive collapse mitigation guidelines to be applied for all federal buildings in the USA. The document provides a flow-chart methodology to determine whether the facility under consideration requires detailed verification for progressive collapse. If the risk of progressive collapse indeed needs to be further considered, the document provides a threat independent procedure, following the design strategy for a load case consisting of a local initial failure (alternate load path). The document allows for sophisticated nonlinear and/or dynamic procedures, but describes in detail only a static linear procedure for progressive collapse mitigation. The combination between dead and live loads to be considered is specified, and a dynamic amplification factor of 2 is specified for static analyses, in order to account for dynamic inertial effects. The triggering event to be considered is the failure of one ground floor column. The static linear procedure actually consists in a sequence of static linear computations, eventually yielding an estimate of the extent of damage in the structure. This extent is then mirrored with the region in which the guidelines consider damage to be tolerated, in order to validate the design, or point to further reinforcements of the structure. Irrespectively of the validity of the underlying assumption for the GSA static linear procedure, these guidelines are among the most complete, in that they instruct the practitioner in all steps of the design process. Only the DoD (Department of Defense) guidelines, provide such details in the procedures to be applied.

### **Department of Defense (DoD) guidelines**

In June 2005, the United States Department of Defense issued its latest guidelines for progressive collapse prevention. Buildings are categorized depending on the required level of protection. When a very low or low level of protection is required, the safety of the structure is ensured through horizontal and vertical ties, while an alternate path approach is prescribed, in addition to the ties for higher protection levels. A step-by-step procedure is provided for a linear static analysis, for a non-linear static analysis, and for a non-linear dynamic analysis. The load combination, involving dead, live and wind loads, is specified, along with a dynamic amplification factor of 2 for static analyses. The DoD step-by step procedure for linear static analysis is similar to the GSA procedure in its general philosophy. The main differences lie in the choices for material behavior used in the simulations, and in the fact that the static and dynamic non-linear procedures are detailed in the DoD guidelines.

### **British standards**

British standards rely on tying force provisions to ensure safety against progressive collapse. If these requirements cannot be met, an alternate load path analysis is specified. This standard suffer from two deficiencies. The first one is that they do not take the sections and connections ductility into account, and it has been shown elsewhere that these provisions may lead to unrealistic ductility demands for the beams sections and connections. Furthermore, in the cases where an alternate load path analysis is to be performed, neither standards specify any computational procedures. Only the loads and final requirement are specified. Any well validated alternate load path procedure thus appears as an added value to the British standards.

### **Eurocodes**

The Eurocodes also adopt the three approaches discussed so far. A classification of buildings into four classes is provided, based on the consequences if collapse were to occur. For the lowest class, no progressive collapse requirements are to be met. For the second class, only horizontal tie force requirements are specified. For the two remaining classes, not only should tie requirements be met, but the structure also needs to be designed for the loss of a vertical load bearing element, with damage not exceeding a specified region. If the damage is too extensive, the vertical load bearing element is considered as a key element, and should be designed to withstand an additional pressure of 34 kN/m<sup>2</sup>. Again, no computational procedure is specified for the alternate load path analysis.

### **U.S. National Institute of Standards and Technology (NIST)**

The document released by NIST in February 2007, entitled “Best Practices for Reducing the Potential for Progressive Collapse in Buildings”, does not purport to provide detailed numerical procedures for progressive collapse simulation. Instead, it offers an overview of the approaches for progressive collapse mitigation, some general guidelines for structural integrity, and a review of available standards for design against progressive collapse, such as the GSA or DoD documents.

### **International Atomic Energy Agency (IAEA) Safety Standards NS-G-1.7**

IAEA goes directly to give a general consideration and recommendation against internal or external explosions and mentioned that Structures, systems and components important to safety are required to be designed and located, consistent with other safety requirements, so as to minimize the likelihood and effects of internal fires and explosions caused by external or internal events. The capability for shutdown, removal of residual heat, confinement of radioactive material and monitoring of the state of the plant is required to be maintained. These requirements should be met by the suitable incorporation of redundant parts, diverse systems, physical separation and design for fail-safe operation such that the following objectives are achieved

For protection against explosions, the following steps should be taken, in order of priority:

- (a) Prevent explosions from occurring;
- (b) Minimize the risk of an explosion, if an explosive atmosphere cannot be avoided;
- (c) Implement design provisions necessary to limit the consequences of an explosion.

Item (c) should only be necessary in exceptional cases, in which items (a) and, (b) cannot be achieved.

### **National Fire Protection Association (NFPA)**

In the meeting of “Technical Committee on Explosives” on August 1-2, 2011, they did not specify any analysis method or criteria, but added a new text for NFPA-495, chapter 11 as follow:

The International Society of Explosives Engineers (ISEE) Blast Vibration and Seismograph Section provides a forum for the discussion of issues related to ground and air vibration from mine, quarry and construction blasting. The Vibration Limits Technical committee was established to promote the use of uniform safe ground and air vibration levels for blasting in mines, quarries and construction. The committee recognizes that reasonable and scientifically based levels and practices are critical for successful blasting projects and protection of the nearby public and property. It is the hope of this committee that this proposal will help improve the uniformity of regulatory practices between jurisdictions and help prevent the promulgation of unrealistic regulations.

The ISEE, through the Blast Vibration and Seismograph Section has developed two documents that will form the basis for the proposed change:

- (a) "Performance Specifications for Blasting Seismographs" (2000)
- (b) "Field Practice Guidelines for Blasting Seismographs" (1999)

The document "Performance Specifications for Blasting Seismographs" deals with the accuracy of blasting seismographs from a mechanical and electronic perspective. The second document "Field Practice Guidelines for Blasting Seismographs" recommends field deployment practices.

### **Egyptian Code of Practice for Design Reinforced Concrete Structures (ECP)**

It is absent in ECP any data or criteria showing how the designer can consider the explosions loads and blast air pressure in the buildings design.

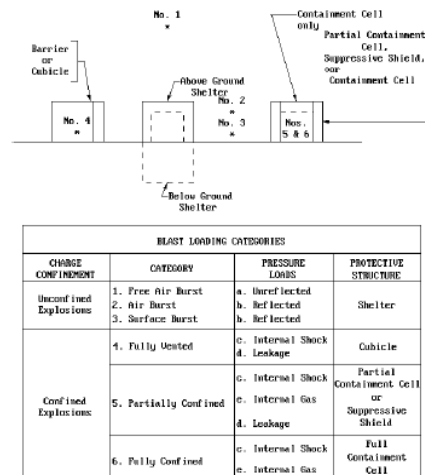
### Unified Facilities Criteria (UFC 3-340-02) December 2008

Starting from this standards we will find a specific method to analyze any part of building like masonry walls, reinforcing masonry walls, retaining structures, facades with or without opening and super structures against explosions, and how we can construct suitable connections to prevent or at least reducing the progressive collapse of the building. UFC 3-340-02 mentioned clearly that, blast loads on structures can be divided into two main groups based on the confinement of the explosive charge (unconfined and confined explosions) and can be subdivided based on the blast loading produced within the donor structure or acting on acceptor structures. These blast loading categories are illustrated in Figure (3). Figure (3) gives the six blast loading categories possible. Figure (1) also shows the five possible pressure loads associated with the blast load categories, the location of the explosive charge which would produce these pressure loads, and the protective structures subjected to these loads.

The blast loading on a structure caused by a high-explosive detonation is dependent upon several factors:

- (1) The magnitude of the explosion.
- (2) The location of the explosion relative to the structure in question (unconfined or confined).
- (3) The geometrical configuration of the structure.
- (4) The structure orientation with respect to the explosion and the ground surface (above, flush with, or below the ground).

The procedures presented here for the determination of the external blast loads on structures are restricted to rectangular structures positioned above the ground surface where the structure will be subjected to a plane wave shock front. The procedures can be extended to include structures of other shapes (cylindrical, arch, spherical, etc.) as well as structures positioned at and below the ground surface.



**Fig.3 Blast Loading Categories**

As mentioned in the abstract that the main aim of this paper how can implement a simplified method to calculate the blast effect on the reinforced concrete structures or select a most standard close to the Egyptian Code. We can observe from the above clause “Codes and Standards” that UFC 3-340-2 the only standard has a clear recommendations and has an analysis method by using Time History Analysis during study the explosion effect.

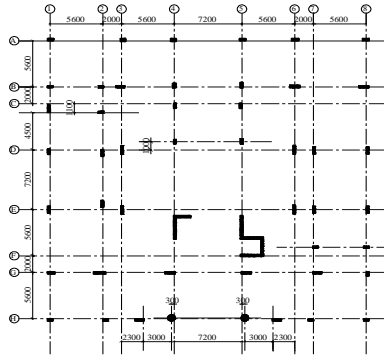
### MODEL DEVELOPMENT

The structure selected for this study is an existing structure with bullet proof glass façade and it is consisting of 5 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.

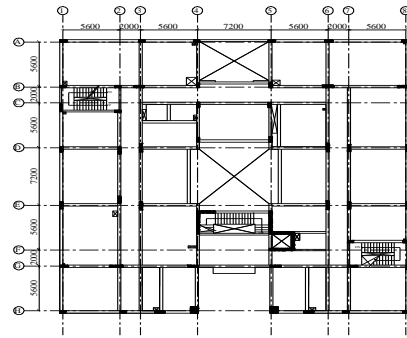
The floors layout and dimensions as shown in Figure (4).

The structural system of the building was made of reinforced concrete frames. The common beam size used is 300X600 mm; 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.

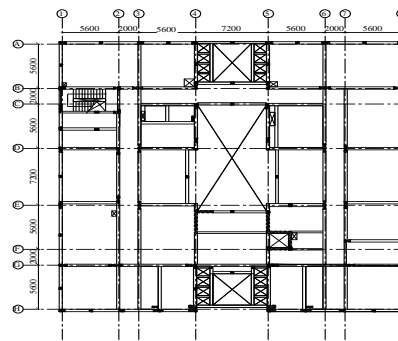




**Fig. 4-a Columns and Axes**



**Fig. 4-b Typical Floor Layout**



**Fig. 4-c Roof Floor Layout**

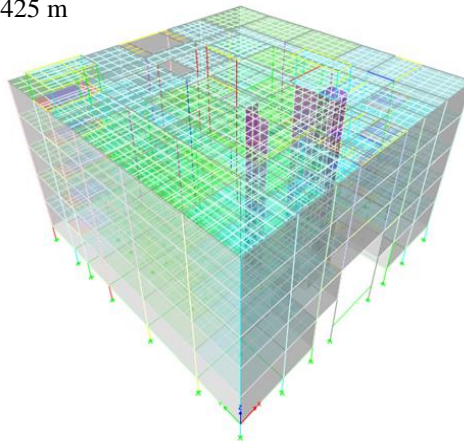
#### **Modeling of frame**

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 (5) shows the 3D model of the frame building using ETABs.

#### **Floors Elevation**

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



**Fig. 5 3D Model for Frame Building by ETABs**

## Computational Study

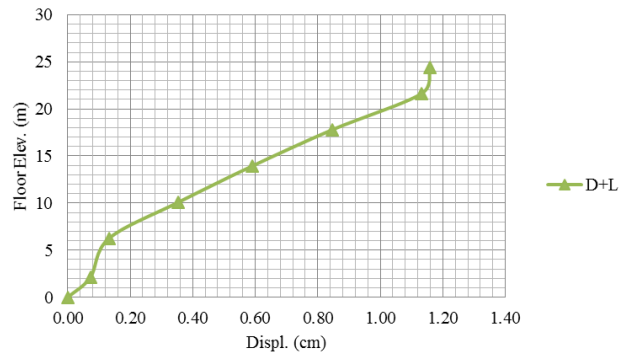
The computational study which will be presented through this paper will cover three regulations GSA, Eurocodes, and UFC 3-340-02 to get which one is more closed to realistic case.

**Table 1. Blast load Simulation in GSA, Eurocodes, and UFC**

Regulation	Blast Simulation	Blast Load
GSA	Static nonlinear analysis and P-Delta effect is considered.	Increase the amplification factor to be 2 for dead and live load combinations. Dead and live loads are applied on all structural elements.
Eurocodes	Static linear	Uniform Pressure = $3.40\text{t/m}^2$ applied on a key structural elements (in this study key structural element is the core).
UFC-3-340-02	Time – History analysis, as per specified in UFC.	As mentioned and specified in regulation and it will depend in bomb weight, and ground distance. Blast loads will be applied on external façade or exterior walls. Blast load added in combination of dead load and live load.

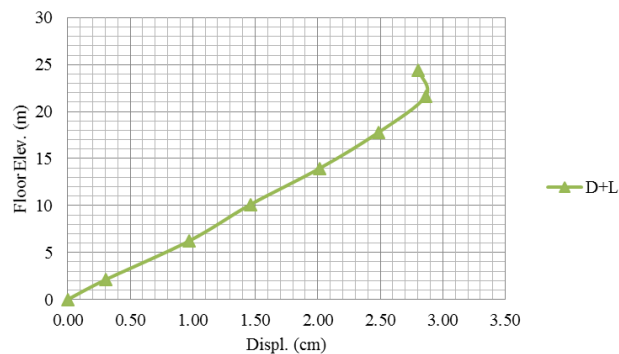
The stories displacements in accordance with select regulations mentioned above will be illustrated through the following charts:

### 1<sup>st</sup> regulation: General Services Administrations (GSA) Progressive Collapse Guidelines 2003



**Fig. 6 Floors Displacement According to GSA**

### 2<sup>nd</sup> regulation: Eurocodes Standard



**Fig. 7 Floors Displacement According to Eurocodes**

### 3<sup>rd</sup> regulation: Unified Facilities Criteria (UFC 3-340-02) December 2008

In UFC regulation blasting calculations are depending on structure height, charge weight, and ground distance. All these factors are taken in consideration and presented in Table-2.

**Table 2. Maximum Pressure Applied on 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

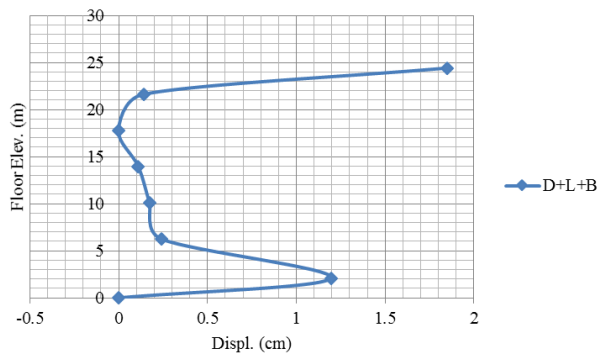
### Floors displacement time

The stories displacement time will show only for listed cases mentioned in (Table 3).

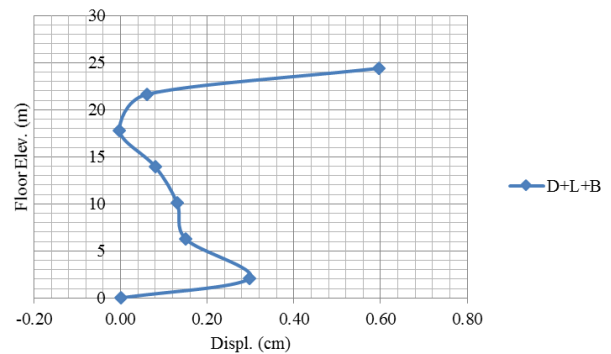
**Table 3. Selected Blast Load Cases**

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

### Floors displacement charts

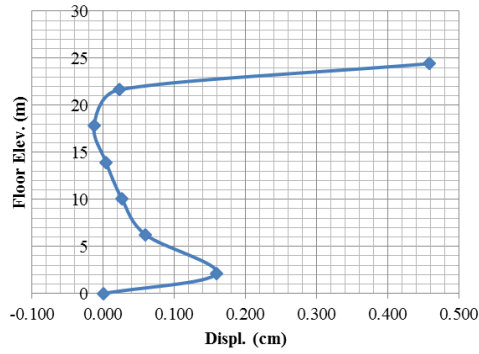


**Fig.8 Case 1 (W= 500Kg, R= 10m)**

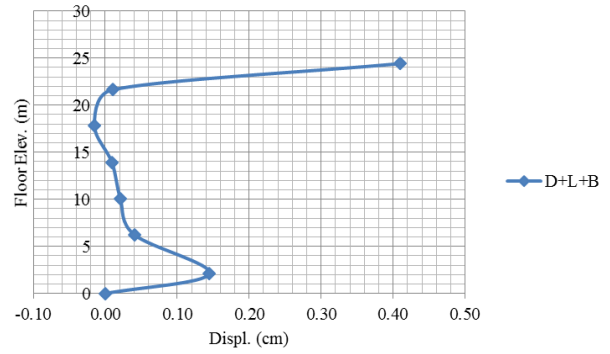


**Fig.9 Case 2 (W= 500Kg, R= 20m)**

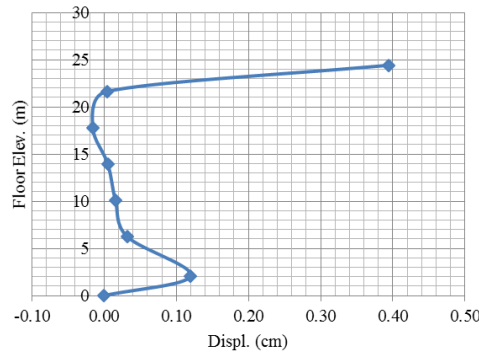




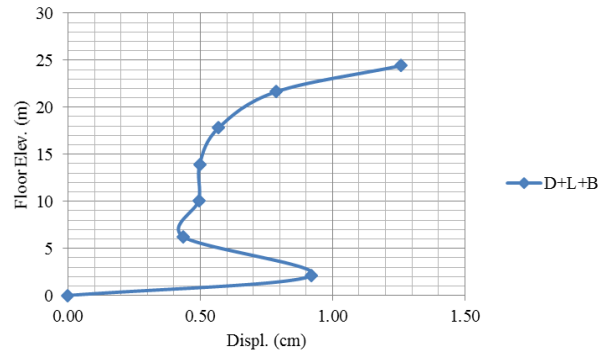
**Fig.10 Case 3 (W= 500Kg, R= 30m)**



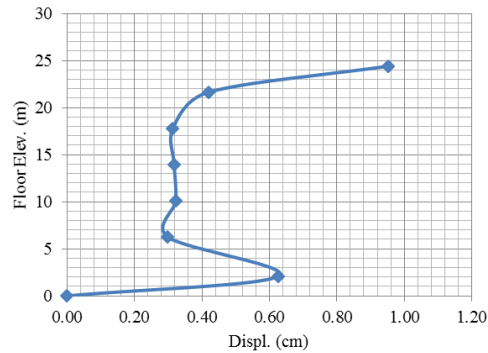
**Fig.11 Case 4 (W= 500Kg, R= 40m)**



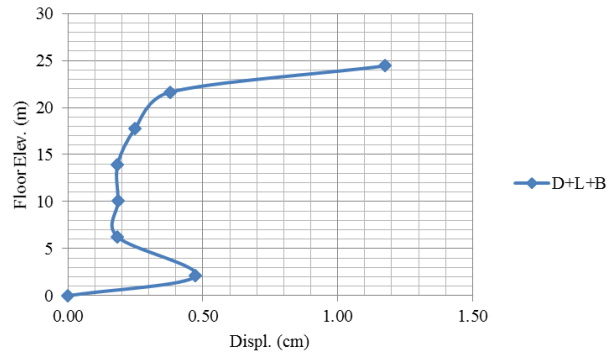
**Fig.12 Case 5 (W= 500Kg, R= 50m)**



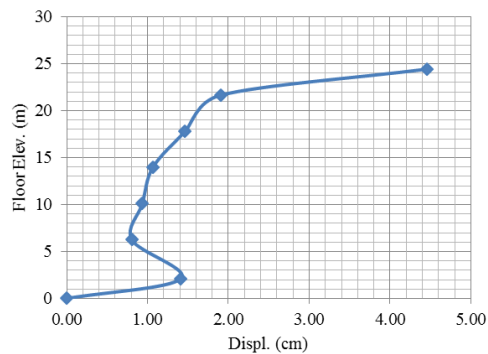
**Fig.13 Case 6 (W= 3000Kg, R= 30m)**



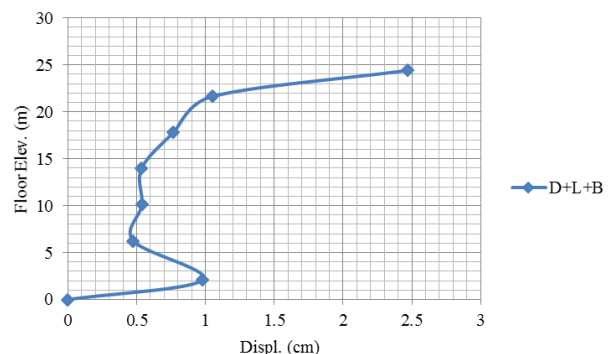
**Fig. 14 Case 7 (W= 3000Kg, R=40m)**



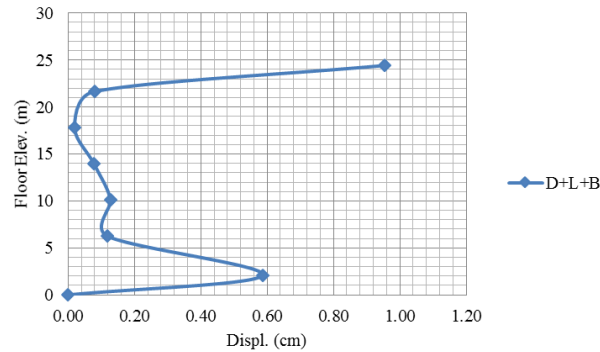
**Fig. 15 Case 8 (W= 3000Kg, R= 50m)**



**Fig.16 Case 9 (W=5000Kg, R= 30m)**



**Fig.17 Case 10 (W=5000Kg, R= 40m)**



**Fig.18 Case 11 (W=5000Kg, R= 50m)**

## RESULTS AND DISCUSSION

Based on what shown from displacement values through above charts, the following remarks are observed:

- 1- GSA Regulation
  - Blast load is not specified just increase the amplification factor for dead and live combination which means that the charge weight and ground distance are not taken in consideration.
  - Blast loads direction cannot be determined because it is considered in a combination of vertical loads.
  - Maximum displacement is 1.13 cm and occurred at elevation 21.65 m, while maximum displacement occurs normally at lower floors for this study.
- 2- Eurocode Standards
  - Blast load is not specified as a uniform pressure equal to  $3.40 \text{ t/m}^2$  and applied on structural elements bearing vertical loads or in key structural elements like cores and shear walls.
  - If the uniform pressure applied on vertical structural elements it is necessity to distribute the pressure as per stiffness and spacing between it, or choose the extreme and applied the pressure on cores or shear walls. In case of applying on cores and shear walls it will apply in X and Y directions.
  - Blast uniform pressure is implemented in vertical load combination.
  - Maximum displacement is 2.80 cm and occurred at elevation 21.65 m, while maximum displacement occurs normally at lower floors for this study.
- 3- UFC-3-340-02 Regulation
  - In this regulation the analysis is based on blast wave which is subjected directly on external walls or facade.
  - As illustrated in above charts and table-1, analysis procedure based on time-history analysis which allows to study the blast effect on each side of the building at any direction in same time.
  - Maximum displacement is achieved in lower floor of the building which is matching with blast free air blast phenomena.
  - Displacements value is varied based on the bomb weight and ground distance.

## CONCLUSIONS

Based on what mentioned above in results and discussion most realistic regulation is (UFC-3-340-02), which is applicable to use for any type of buildings. The used equations to calculate the displacement are un-factored which give a chance to merge it with Egyptian Code of Practice for Design Concrete Structure equations and can be verified by Egyptian Code displacement limits.

## ACKNOWLEDGMENT

The author Ahmed A. Bayoumey thanks Prof. Dr. Walid A. Attia for the many valuable comments to the manuscript.

## 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.

## REFERENCES

1. Fatih Tahmilci, "Analysis of Blast Loading Effect on Regular Steel Building Structures" in Middle East Technical University, Master in Science Thesis, DECEMBER 2007.
2. M. Laissy and W. Attia, "Finite Element Analysis of Blast and Low-Velocity Impact on Sandwich Panels with Multiple Suppressive Cores" in Cairo University, Faculty of Engineering, Doctor of Engineering Thesis, 2010.
3. H.S.Lew, "Best Practices Guidelines for Mitigation of Building Progressive Collapse" in National Institute of Standards and Technology, Gaithersburg, Maryland, U.S.A 20899-8611.
4. P. Bouillard, "Progressive collapse comparison of main standards formulation and validation of new computational procedures", in Dissertation originale présentée en vue de l'obtention du grade de Docteur en Sciences de l'Ingénieur, 2008-2009.
5. International Atomic Energy Agency (IAEA) Standards Series, "PROTECTION AGAINST INTERNAL FIRE AND EXPLOSIONS IN THE DESIGN OF NUCLEAR POWER PLANT", Safety Guide, NS-G-1.7.
6. National Fire Protection Association, "TECHNICAL COMMITTEE ON EXPLOSIVES – NFPA", AUGUST 1-2, 2011.
7. Unified Facilities Criteria (UFC), "STRUCTURES TO RESIST THE EFFECTS OF ACCIDENTAL EXPLOSIONS", UFC 3-340-02, DECEMBER 2008.
8. American Concrete Institute 318 (ACI 318)
9. United States General Services Administration (GSA), 2003.
10. Department of Defense (DoD), 2005.
11. British Standards (BS 8110).
12. National Institute of Standards and Technology (NIST), 2007.
13. Egyptian Code of Practice for Reinforced Concrete Design, 2012.