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# Protection of Public Buildings against the Effects of Explosions

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**ملخص البحث**
في الآونة الأخيرة كثر تعرض الأبنية العامة لحوادث التفجير بمختلف أنواعها مما سبب الكثير من الأضرار المادية و البشرية، وكذلك تبين قصور التصاميم المعمارية والإنشائية للمباني القديمة والحديثة في مقاومة الانفجار، لذلك اختص هذا البحث بدراسة أساليب حماية الأبنية العامة من آثار الانفجار. يقدم هذا البحث تعريف الانفجار وأنواعه ونواتجه ومراجعة شاملة لأهم الأبحاث المنشورة محليا وعالميا في هذا المجال. ويستعرض البحث الأساليب والاستراتيجيات الخاصة بحماية الأبنية من الانفجار سواء ما يتم مراعاته أثناء مرحلة التصميم في المباني قبل الإنشاء أو ما يتم تنفيذه في المباني القائمة. كما يحتوي البحث على دراسة لحالتين لمبنيين تعرضا سابقا للإنفجارات مما تسبب في أضرار بالغة، هما مسجد النداء في العاصمة العراقية بغداد والحالة الثانية مبنى القنصلية الايطالية في العاصمة المصرية القاهرة، ويقدم مقترحات تفصيلية للحماية من إنفجارات أخرى محتملة. وأخيرا يتم عرض أهم الملاحظات والاستنتاجات التي تم الوصول إليها، ويقدم البحث توصيات واقتراحات لدراسات مستقبلية في هذا المجال.

## Abstract
Recently, many public buildings are increasingly exposed to various types of explosions which have led to loss of human lives and enormous physical damages. The increase of building damage is attributed to the fact that the architectural and structural design of existing buildings did not take into consideration protection against explosions. This paper presents the methods and strategies for protection of buildings from explosions, both during the design phase of new buildings, such as the choice of the site, as well as measures taken to provide blast resistance to existing buildings such as the establishment of barriers of different types around the building. A comprehensive review of the most important researches published locally and internationally in this field is given. Two public buildings that were previously exposed to explosions are studied and analyzed: the first is Al-Nida mosque in the Iraqi capital Baghdad and the second case is the Italian consulate in the Egyptian capital Cairo. The study includes proposals for protection of the two public buildings against explosions. The main conclusions are presented and recommendations and proposals for future studies are given.

**Keywords:** Explosion, Blast effect, Blast Protection, Confrontation distance, Barrier.

## 1. Introduction
Recently, many terrorist attacks occurred in countries around the world that were based on bombing of public buildings, aiming to cause the largest possible loss of lives and damage. This made it necessary to direct effort and research for development of procedures to avoid the drastic effects of explosions. Preventing explosion is difficult, even with availability of modern methods of explosives detection because of the advanced strategies of terrorist attacks. Bombing methods include projectiles, explosive devices, car bombs, fuel tanks and others. The damage varies depending on many

factors: the source of explosion, force of the explosion, method of implementation, type of structure, architectural shape and height, construction materials, quality control, condition of surrounding fence and gate, as well as security measures. All of these factors as well as the lessons learned from previous attacks should be considered in order to provide maximum protection to the building or to reduce as much as possible the damage caused by the explosion.

An explosion is defined as a large-scale, rapid and sudden release of energy. Explosions can be categorized as physical, nuclear or chemical events [1]. Explosive materials are solids, liquids or gases; solid explosives are high explosives producing high blast effects [1]. Explosion wave phenomenon can be defined as the area of expansion, spread of pressure and supersonic speed of the explosion center [2]. The dynamic pressures exerted by blast explosions on the affected surfaces are impulsive loads with significant potential energy which sets damage-causing vibrations in the structure. The dynamic pressure wave has a time history consisting of positive and negative phases, as shown in Fig. 1 [2]. The primary effect of a blast wave on a structure occurs during the positive phase, where pressure values are high. In the negative phase or the negative pressure, the air is absorbed towards the center of the blast, which leads to the fragmentation of walls or structural and architectural elements in the area of the explosion. These fragments flying at high speed around the center of the explosion as well as collapsed parts of the building may lead to human injuries and mortalities close to the explosion [1].

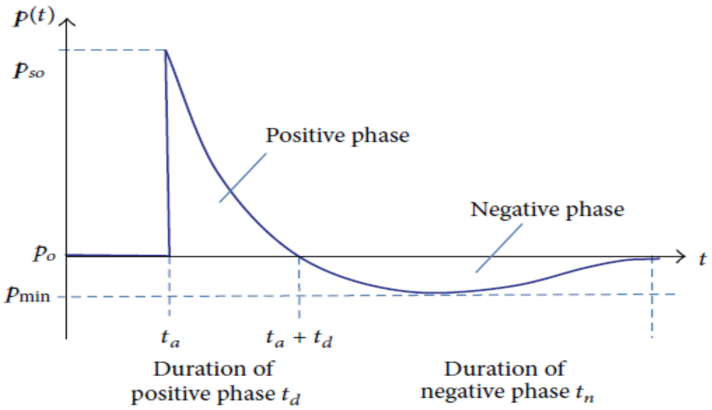


Fig.1. Blast wave pressure – time history [2]

One of the largest chemical explosions occurred in China in 2015 in the city of Tianjin. On August 12, a fire started in the warehouses where thousands of tons of flammable chemical materials were stored. Extinguishing fire with water led to a series of large reactions that led to a series of explosions that lasted for 4 days [3]. Explosive size was estimated at about 21.9 tons of TNT, and the explosion which was heard for several kilometers. Official reports recorded 173 deaths and 797 injuries, in total 304 buildings were damaged, 12 428 cars, 7533 multimedia container with the impact of 17000 units of housing for a distance of 2 kilometers and more than that of the site with broken glass and damaged roofs as shown in the Fig. 2 [4], in addition to the damage to the environment.


Fig. 2: Tianjin explosions in 2015 [4]

Several methods and techniques can be applied for protection for public buildings against the effects of explosions. These techniques aim to reduce as much as possible the damage caused by the explosions to the building and consequently human injuries, preventing the collapse of buildings after the explosion and possibility to continue usage of the building after the explosion [5]. The techniques can be divided into two main types according to the time when the technique is implemented, namely the design phase and the post-construction phase. The first phase of the design is the most important and most effective one and helps in reducing the costs of protection. This phase determines the most important technique for protecting buildings, which is the distance of confrontation [5]. Also in this phase the type of the structure, materials used in the structure, type of external walls and natural fenders, etc. are selected which have great influence on the blast resistance of the structure [5]. The second phase after the building construction and use is complementary and depends on the first phase, it is also more expensive to implement than if protection measures were considered from the beginning [5].

This research paper aims to present the classic and modern methods of protecting public buildings and structures and reducing the damage occurring in case of explosions. In the following sections, review of research published locally and internationally is given, and methods for protecting public building against explosions are overviewed. Study cases of several public buildings that experienced explosions are given and analyzed, as well as proposals to immunize the building and, to provide maximum protection against the effects of the blast.

## 2. Literature Review

Many researches discussed explosions, their types and their products, analysis of attacks and field tests. Ngo et al. [1] presented definition of explosion and classified its types into the physical, chemical and nuclear explosions. The characteristics of each type are identified according to the method of operation or sensitivity to flammability to primary and secondary explosives [1]. Andreou et al. [2] explained the explosion wave phenomena as an area of expansion of pressure that spread rapidly at the speed of sound from the center of the explosion and after the air explosion, and defined the two stages of negative and positive stages or negative and positive pressure [2]. Subrami et al. [6] applied numerical and structural analysis to evaluate the damage occurring in structures due to explosion effects.

Protection of structures against explosions was discussed in the published literature. Smilowitz [7] suggested protection of the perimeter of the building by increasing confrontation distance, by placing counter barriers of various kinds, remove one from the path of traffic and convert it into an enlarged pavement, keep the car park away from the building, protection of the building facade that is the first line of defense to protect the building against the impact of the explosion. Arablouei and Kodur [8] also discussed the first line of defense to protect steel buildings from fire damage resulting from the explosion so as to prevent buildings from collapse. Abdollahi and Rashid [9] classified the protection levels into three sections. The first section deals with the neighborhood around the building, the types and height of constructions and the intensity of activities such as traffic, the second section is surrounding the building perimeter protected by providing a safe distance, construction of smaller buildings around the main building, adding natural barriers and other obstructions to distort waves, and the third section concerns the building itself [9].

Modern blast protection methods were presented by several researchers. Chabin and Pitiot [10] investigated mitigation of explosion wave by water, the water walls proved to be as efficient and sometimes more effective than solid walls. The mitigation process of the water wall depends on the ratio of the weight of the explosive to the weight of the water, the distance between water and explosive charge and the thickness of the water wall [10]. Chundawat et al. presented overview of blast protection techniques for structural elements using composite materials [11]. Muszynski and Purcell [12] strengthened existing structures using high-strength composite materials in order to enhance reinforced concrete and construction walls against blast pressure. The composite materials used were carbon fiber reinforced plastic (CFRP) with three layers 0/90/0 and fabrics made of fiber glass knitted and dry with two axes 0/90 [12]. Bedon et al. [13] studied the requirements that must be taken into account when installing explosion-proof glass. Yu et al. [14] used multi-layer explosion resistant doors and a flat separating the layers of circular rings from the inside, this stratification works to absorb and store energy temporarily better, these rings are based on the number of rings formed.

## 3. Methods for Protection of Buildings from Explosions

In the past, the technology of fortification and protection of buildings against explosions were limited to military buildings and embassies. However, increasing attacks and changing tactics that have been targeted at embassies, commercial buildings, economic groupings and the residential building, led to the transfer of technology to protect buildings against the effects of the explosion to civil applications in 1995 [15]. Even the developed countries are not immune to this explosion, which may be the result of terrorist attacks or technological errors or another. Therefore, caution must be taken account of an explosion at the building design, taking all precautions, laws, security measures to protect public buildings from this explosion of all kinds.

The methods of protecting public buildings from external explosions can be classified according to their priority and importance as the following methods.

### 3.1Confrontation distance

The most significant parameters for blast loading computations are the explosive amount and the distance of the explosion point from the structure. Increasing the distance between the blast source and the target surface decreases the peak pressure value and velocity of the blast wave, as shown in Fig. 3 [16]. The importance of the distance of confrontation can be observed from Table 1, which lists the amount of change in pressure reflection (in MPa) resulting from the explosion with the different distances of confrontation (R) and the charge as equivalent TNT weight (W). Two amounts of TNT different in weight can produce the same pressure for two different distances. The building location determined in the first stages of architectural design should provide the greatest possible distance of confrontation. Maintaining the distance of confrontation is the most effective way and the lowest cost to protect the buildings from the explosion especially if the buildings are not designed to resist explosions [5]**.** To increase the distance of confrontation in buildings that do not have that distance, some obstacles can be added that increase the distance and include the walls of the explosion [5], or removing one track from the traffic movement and turning it into an extended dock in the far direction as well as setting the car parking away from the building [6].

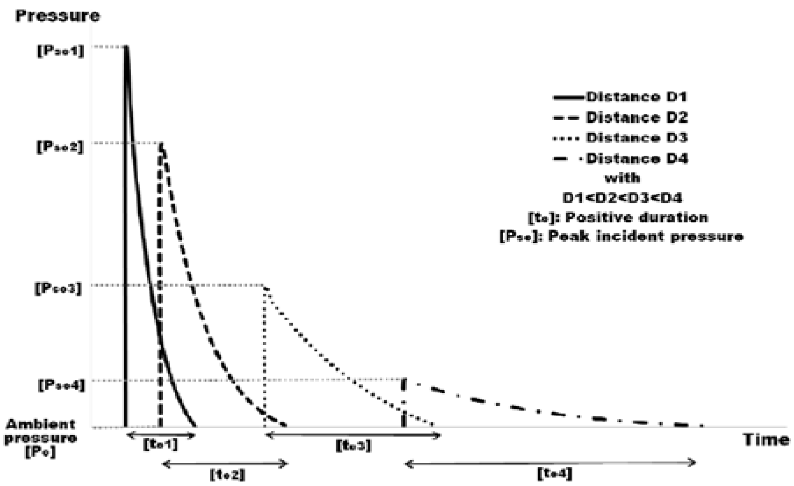


Fig. 3: Influence of distance on the blast positive pressure phase [16]

Table 1: Pressure reflection from explosions with different distances of confrontation and equivalent TNT weights [1]

| W / R | 100 kg TNT | 500 kg TNT | 1000 kg TNT | 2000 kg TNT |
|---|---|---|---|---|
| **1m** | 165.8 | 354.5 | 464.5 | 602.9 |
| **2.5m** | 34.2 | 89.4 | 130.8 | 188.4 |
| **5m** | 6.65 | 24.8 | 39.5 | 60.19 |
| **10m** | 0.85 | 4.25 | 8.15 | 14.7 |
| **15m** | 0.27 | 1.25 | 2.53 | 5.01 |
| **20m** | 0.14 | 0.54 | 1.06 | 2.13 |
| **25m** | 0.09 | 0.29 | 0.55 | 1.08 |
| **30m** | 0.06 | 0.19 | 0.33 | 0.63 |

### 3.2 Explosion walls

The walls of the explosion walls are the first line to protect the buildings against the blast in addition to increasing the distance of confrontation. Reinforcing the external fencing to be explosion resistant can be achieved by adding extra precast movable walls that can be easily installed and removed, water walls, Hesco barriers or else through enhancing the walls by FRP application or reinforcing steel [17, 18]. Hesco barrier and blast water wall are shown in Figs. 4 and 5, respectively [19, 20].

Fig. 4: Installation of Hesco barrier [19]

Fig. 5: Water wall [20]

### 3.3 Car traffic

Explosive charges used in high-impact attacks cannot be carried by individuals, so the vehicles play a key role in these attacks [5]. Therefore, care should be taking to establishing artificial and natural barriers and any other procedures from driving cars away from the building, as well as through the privacy of the building and the surrounding area. These include setting up barriers of all kinds (low walls, lanterns, active wedge, beam barriers, cable-based systems, surface planter barriers, other barriers), change the route of vehicles and banning of parking [5].

### 3.4 Building facade

The facade of the building is the first defense line of the building facing the explosion pressure wave. It consists of several parts including doors, windows, external cladding and decorative elements, interconnection materials and others. All components of the building facade should provide the strongest resistance to the explosion.

### 3.5 Architectural and structural design

In the stage of building design, designers should choose the most efficient and economic methods to protect the building and reduce the effects of the explosion. Considerations such as the distance of confrontation, the construction site, interface shape, the necessary stiffness of the structure and other important strategies work together or individually to provide the best architectural shape and structural elements to be resistant to blast loads [17].

### 3. 6 Use of composite materials

Composite materials can be used to strengthen buildings against the effects of the explosion in several ways, including: use of high strength and high performance concrete, adding a fiber-polymer (FRP) external layer to the concrete structures, flexible plastic coating, the use of fiber-shaped fabric (polymer catcher system), reinforcing and arming of columns using FRP materials, using fiber in the form of sandwich panels or honeycomb sheets, adding metal foams, attaching steel sheets or strips to protect the walls from collapse [18].

### 3.7 Insulation of steel buildings with fire resistant materials

Steel element begins to lose its strength at temperature of 316°C, when the temperature reaches 538°C, it loses 50 percent of its strength, so it is very important to protect the structure from high temperature [17]. Use of protection layer composed of gypsum and Portland cement is useful.

### 3.8 Monitoring and early warning integration

The use of electronic monitoring systems of various kinds, in addition to security men to monitor any strange movement and the treatment of foreign objects that are placed around the building, it has a very serious effect, it can reduce the loss of human lives and property.

## 4. Design Solution for Blast Protection of Selected Cases

Two study cases are studied for public buildings which were previously targeted by explosions and huge damage resulted. The first case is the mosque of Al-Nida in the Iraqi capital Baghdad and the second case is the Italian Consulate in Egypt's capital. Proposals are given for protection of these buildings against expected explosions. Selection of the most suitable protection method for each cases is based on analysis of the damage occurred to the building in its previous explosion, as well as on the study of possible methods and strategies for blast protection.

### 4.1 Case study 1: Al-Nida mosque in Baghdad

Figure 6 is an aerial picture showing the location of Al-Nida mosque, Mufti mosque and the explosion center. The proposals for protection of the mosque against explosions are shown in Fig. 7 and the needed quantities are calculated and are listed in Table 2. Construction of additional facades consisting of composite materials up to a height not less than two floors, to the eastern facade of Al-Nida Mosque in the Iraqi capital of Baghdad, which consists of eight castles in the height of the building

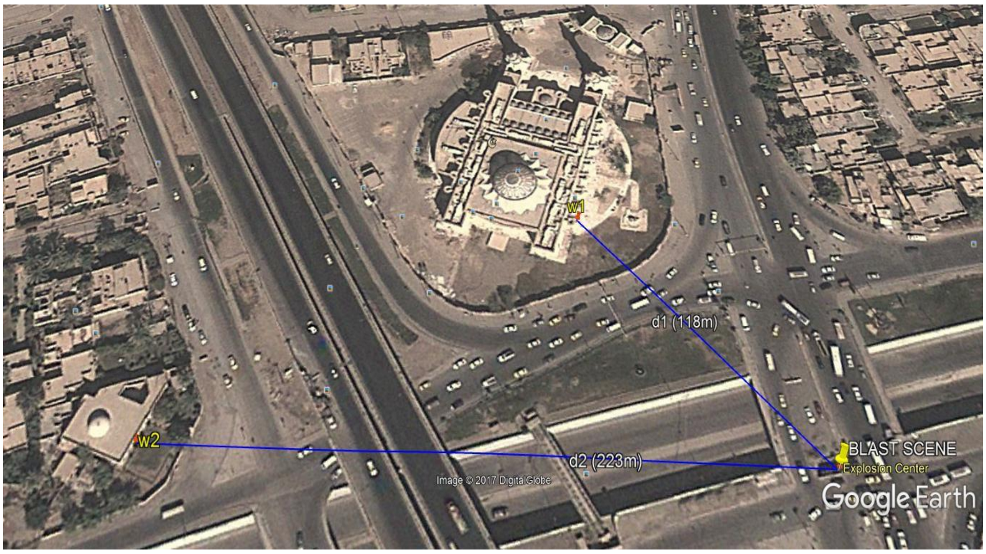


Fig. 6: Location of Al-Nida mosque, Mufti Mosque and the explosion center [21]

Fig. 7: Proposed barriers around the building [21]

Table 2: Proposals for protecting Al-Nida mosque against explosions

| No. | Description | Quantity |
|---|---|---|
| 1 | Construction of reinforced concrete barrier wall 3 m height, surrounding the building inside the existing fence on three sides of the building. The fourth side is a concrete block from the outside approximately the houses near the mosque. | 480 m |
| 2 | Adding radiant barriers around the perimeter of the building from three sides of a fixed type, which is not less than 3 m above the sidewalk adjacent to the building and is close to each other so that no car can enter through them. | 360 m |
| 3 | Addition of effective barriers moving vertically at the entrances of the building to prevent the cars from penetrating inside. | No. 2 |
| 4 | Reinforcing the main windows by adding a second frame over the old frame of iron of a rectangular section with good installation, with the addition of glass films or Mylar films for the entire building from the inside. | $500m^2$ |
| 5 | Change the openings of the main and exterior doors of the building to the outside. | No. 5 |
| 6 | Add a control panel with cameras around the building with an alarm clock to monitor any strange movements around the building, and to warn the passengers and deal with the danger if possible. | Lump-sum |
| 7 | Enhance the strength of the additional interface because of the gaps inside it by injecting the cement to be able to reverse the wave of the explosion (L=50m-W=10m). | Lump-sum |
| 8 | Add natural barriers inside the garden building from the east and west side and its absorption and reverse part of the wave of the default explosion of these palm trees barriers. | Lump-sum |

## 4.2 Case study 2: the Italian Consulate in Cairo

Proposals for protection of the consulate building against explosions are shown in Fig. 8. The procedures are explained, and the required quantities are calculated and are listed in Table 3 where the needed quantities are calculated and are given.


Fig. 8: Italian consulate building plan and proposed protective barriers [21]

Table 3: Proposals for protecting the Italian Consulate building against explosions

| No. | Description | Quantity |
|---|---|---|
| 1 | Providing a counter space to the building, especially to the east of the previous explosion by removing the traffic from the street adjacent to the facade and by 3 meters by replacing the barrier in the street, which consists of square steel columns and wires. The method of replacement by addition of cylindrical plugs at small distance to ensure that the vehicles do not enter between them, the type of fixed grounded concrete so good that if you hit a car prevents penetration. | 110m$^2$ |
| 2 | Construction of reinforced concrete wall that rises above the fence at a height of 1 m and a width of 15 cm connecting with the adjacent columns and along the fence to increase the protection of the building behind the fence. The work includes removing the iron fence over the old fence and returning it after adding the concrete wall. | 33m$^3$ |
| 3 | Reinforcing external walls with FRP to increase the resistance of the walls on the side of the explosion wave pressure with composite fabric or non-woven k/g fabric (which is more flexible than the foam, cost effective and easy to apply) The height of the fence is 3.20 m with the addition 20 cm for the height of the cloth for fixing it with the foundation of the fence. | 760m$^2$ |
| 4 | Adding concrete barriers in the rest of the building, which does not contain an external fence and at an altitude of 3 m. | 90m$^2$ |

| | | |
|---|---|---|
| 5. | Design glass systems capable of carrying explosion pressure by reinforcing the windows with iron frames from inside. And the choice of laminated glass or so-called Mylar films. Polyester or transparent anti-breaker which is applied in the inner surface of the glass and is considered an effective way to prevent the diffusion of glass beads into the interior. | 600 $m^2$ |
| 6 | Reinforcing the walls around the k/g composite fabric windows to increase the ability of the walls to load the side of the blast wave pressure | 2000$m^2$ |
| 7 | Remove the car garage near the building as much as possible. | Lump-sum |
| 8 | Control the type of vehicles passing around the building by preventing all vehicles carrying more than half a ton from passing. | Lump-sum |
| 9 | Construction of an additional facade of the building and the height of the building, which is of an architectural form close to the building and solid, which prevents the penetration of the potential explosion wave from entering the center of the building, with a distance of (26 m * 9 m). | Lump-sum |
| 10 | Reinforcing the main windows by adding a secondary frame over the old frame of iron with a rectangular section with good installation with the addition of glass films or Mylar films for the entire building from the inside and area of 500 $m^2$. | 600$m^2$ |
| 11 | Install a surveillance system using cameras around the building and surrounding streets to monitor any strange movement and associated with an alarm system to warn the occupants of the building to take the necessary procedures. | Lump sum |

## 5. Summary, Conclusions and Recommendations

Damages resulting from explosions exceed those resulting from earthquakes, so it is necessary to include explosions as additional imposed load on buildings in the structural design phase. Additionally, laws should be issued to consider explosion loads in design of new public buildings that will be built and also provide blast protection for existing public buildings. This paper presented methods to protect existing and newly constructed buildings from the effects of explosions, arranged according to their importance and priorities for implementation. Two actual cases were studied which have been subjected to explosions and suffered severe damage. The studied cases are the Nida mosque in the Iraqi capital Baghdad and the building of the Italian consulate in the Egyptian capital Cairo. After analyzing the buildings to find its flaws in terms of withstanding the explosion, studies were made to select the best methods available to protect them from the explosion.

The most important conclusions and recommendations derived from this study can be summarized in the following points.

1. The first and most important method of protection against the impacts of explosion is to provide a suitable distance for the building and maintain this distance in various ways because the wave of the explosion gradually fades as the distance of confrontation increases.

2. It is necessary to protect the building's glass as it is the weakest point in any building, no matter how far the confrontation is.

3. Add additional facades with an acceptable architectural form consisting of composite materials up to a height not less than two floors, which act in contrast to the absorption of explosion products.

4. Attention to surveillance systems associated with alarm systems to monitor suspicious movements around the building and warn passengers to implement the contingency plan.

5. Issuing special laws to add blast loads to the loads loaded in the design of public buildings. The validity of the building shall be checked to resist the effects of the explosion by exposing the facility to a digital explosion using a modeling program.

6. Documentation of the incident explosions, their motives and effects on occupants and buildings to be lessons learned to facilitate the process of protecting any facility and to identify the weaknesses of buildings to avoid repeated scenarios of collapse of buildings and human damage.

7. Introducing practical or numerical study aimed at manufacturing windows that are resistant to external explosions while at the same time working to relieve the pressure easily in the case of breaking the explosion pressure of the building, to be moveable or steady in case of explosion.

8. Promoting studies to protect the buildings from the explosion using water walls.

## References

[1] Ngo, T., Mendis, P., Gupta, A. and Ramsay, J., 2007. Blast loading and blast effects on structures – an overview, Electronic Journal of Structural Engineering (EJSE) Special Issue: Loading on Structures, 7(1), pp.76-91.

[2] Andreou, M., Kotsoglou, A. and Pantazopoulou, S., 2016. Modeling Blast Effects on a Reinforced Concrete Bridge, Advances in Civil Engineering, Volume 2016, Article ID 4167329, 11 pages.

[3] http://sen.wikipedia.orgwiki2015_Tianjin_explosions

[4] https://i0.wp.com/www.gcint.org/wpcontent/uploads/2016/07/Tianjin-Explosion-081515.jpg?fit=640%2C480&ssl=1

[5] Dusenberry, D.O. (ed.), 2010. Handbook for Blast Resistant Design of Buildings, John Wiley & Sons.

[6] Subramani, T., Devi, K.B., Saravanan, M.S. and Thomas, S., 2014. Analysis of RC structures subjected to vibration using ANSYS. International Journal of Engineering Research and Applications, 4(12), pp.45-54.

[7] Smilowitz, R., 2008. Designing buildings to resist explosive threats. Whole Building Design Guide, pp.18-21.

[8] Arablouei, A. and Kodur, V., 2016. Modeling delamination of fire insulation from steel structures subjected to blast loading. Engineering Structures, 116, pp.56-69.

[9] Abdollahi, S. and Rashid, H., 2016. The role of architecture in designing buildings subjected to blast loads. Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura, 62(1), p.105.

[10] Chabin, P. and Pitiot, F., 1998. Blast wave mitigation by water, Groupe SNPE, Paris, France.

[11] Chundawat, T.S., Vaya, D., Sini, N.K. and Varma, I.K., 2018. Blast mitigation using FRP retrofitting and coating techniques, Polymer Composites, Volume39, Issue 5, May 2018, pp. 1389-1402.

[12] Muszynski, L.C. and Purcell, M.R., 2003. Use of composite reinforcement to strengthen concrete and air-entrained concrete masonry walls against air blast. Journal of Composites for Construction, 7(2), pp.98-108.

[13] Bedon, C., van Doormaal, J.C.A.M., Haberacker, C., Hüsken, G., Larcher, M., Millon, O., Saarenheimo, A., Solomos, G., Stolz, A., Thamie, L. and Valsamos, G., 2015. Recommendations for the improvement of existing European norms for testing the resistance of windows and glazed façades to explosive effects (No. EUR 27554 EN JRC98372 LB-NA-27554-EN-N). European Union.

[14] Yu, Z.L., Xu, P. and Chen, Z., 2017. Nested tube system applicable to protective structures against blast shock. International Journal of Impact Engineering, 102, pp.129-139.

[15] National Research Council, 1995. Protecting buildings from bomb damage: Transfer of blast-effects mitigation technologies from military to civilian applications. National Academic Press.

[16] Demin, G. and Varnitha, M.S., 2016. Structural Analysis of Blast Resistant Structures, International Journal for Scientific Research & Development (IJSRD), Vol. 4, Issue 05, pp.1141-1144.

[17] Nolan, D.P., 2014. Handbook of fire and explosion protection engineering principles: for oil, gas, chemical and related facilities. William Andrew.

[18] Buchan, P.A. and Chen, J.F., 2010. Blast protection of buildings using fibre-reinforced polymer (FRP) composites. In: Blast Protection of Civil Infrastructures and Vehicles Using Composites, pp. 269-297.

[19] https://secure.i.telegraph.co.uk/multimedia/archive/03575/Vodafone-hesco-1_3575220b.jpg

[20] https://www.buildingconservation.com/articles/terrorism/waterwall.jpg

[21] http:// www.google earth pro.com