Accidental Explosions, Beirut ANFO Blast, Ghana Truck Explosion, Global Terrorism Index 2021-22, and Blast Mitigation: A Review

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Abstract. Explosions are continually occurring without ceasing in many parts of the world endangering human lives and seriously affecting the health of infrastructures and facilities. Industry accidental mishaps that occurred recently, like those in Ghana (2022; 17 deaths), Russia (2021; 18 deaths), Beirut (2020; 220 deaths; $8bn economic loss), and Tientsin (2015, 173 deaths; $6.86bn economic loss), indicate the severity of the industrial devastation one could gauge that explosions may cause. Very recently, another industrial blast occurred at a rocket and explosive factory in the capital city of Turkey leading to the collapse of a nearby building and causing 5 deaths and serious injuries to over 50 civilians, is an eye-opener. This article offers a condensed examination of subjects related to explosions, including accidental detonations, the Beirut ANFO explosion, and the Ghana truck explosion. The report findings from the global terrorism index 2021-22 are analyzed and discussed. Additionally, strategies for both active and passive measures to mitigate the impact of explosions on infrastructure and facilities are emphasized. To ensure safety and durability against damage, the structure needs to possess resilience in the face of explosions. Therefore, it is crucial to analyze how the structure responds to extreme loading in order to enhance the design philosophy. Currently, there is still a lack of understanding regarding the mechanism of blast and how it affects masonry structures. Consequently, further research is required to delve deeper into this subject.

1. Introduction

Before the recent catastrophic industrial explosions, such as the explosion at a rocket and explosive factory in Turkey in June 2023, the gas pipeline blast in Russia in November 2022, the truck explosion in Ghana in January 2022, the pipe gas explosion in China in June 2021, and the devastating Beirut blast in August 2020, the focus on designing structures to withstand blast loading was primarily limited to high-profile buildings like embassies, military installations, and petrochemical facilities [1-3]. Engineers and researchers have been focusing on ensuring the structural protection and safety of buildings against explosions due to the disproportionate collapse of structures near the explosion site [4-15]. This concern arises from the fact that even buildings located far away from the explosion can suffer significant damage. Recent years have witnessed attacks on multiple embassies and the use of suicide vehicle bombs to target civilian populations in various countries. Roadside or homemade explosives, like IEDs, are employed to target shopping malls, urban centers, and critical infrastructure and facilities in metropolitan regions. Apart from causing physical harm to structures, explosions carried out using vehicles also generate shrapnel and debris that can result in severe injuries and, in certain cases, fatalities [4, 9, 11-15]. Typically, the extent of harm inflicted upon a building or its various elements as a result of an explosion can range from fixable damages to complete and utter destruction, leading to severe injuries such as traumatic amputation, penetrating trauma, blast lung,

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angina, intra-abdominal hemorrhage, globe rupture, and even fatalities. The existing structural design codes do not take into account intense strain loadings like blasts or impacts, nor do they provide guidelines to prevent their likelihood during construction or the lifespan of the structure [16-25].

Blast loading involves the application of intense pressure over a brief period, typically ranging from microseconds to milliseconds. Compared to quasi-static and other less severe dynamic loadings caused by phenomena like wind, waves, or earthquakes, blast loading is generally more destructive.

Some engineers argue that when designing buildings in densely populated and sensitive areas, it is crucial to take into account the potential impact of blast loading in order to ensure the safety of both structures and occupants.

An explosion is characterized by the sudden release of heat or increase in pressure, resulting in potential harm such as structural damage, injuries, or loss of control [26-32, 48-55]. This can happen in two ways: either by the expansion of a system containing heated gas, leading to a rise in temperature, or by the transmission of a strong pressure wave originating from the explosion's source [28-30]. Although not always present, explosions are often accompanied by the presence of light, noise, and flying debris.

Fig. 1. Exploring the representation of explosions in the process industry for chain reaction effects [34]

In the industrial setting, there has been a focus on predicting, preventing, and reducing the impact of accidental explosions. This has led scientists and researchers to develop more precise definitions that delve into the intricate physical and chemical phenomena underlying these destructive scenarios [28-33]. However, significant discrepancies still persist between fundamental scientific textbooks and international guidelines such as the Yellow Book or the AIChE guidelines of CCPS (2010) [33]. In order to shed light on the continuing discussion, a general classification system is introduced (refer to Figure 1). Figure 1 displays a pathway on the left side that is linked to the occurrence of a chemical reaction known for its swift rate. When it comes to combustion, this occurrence takes place between the fuel and the oxidant, typically air but occasionally other oxidants. To achieve the desired outcome, it is essential to possess predetermined circumstances for the substances involved and processes that expedite the spread of fire (known as the Schelkin effect) in order for an explosion to transpire in an unrestricted or partially restricted setting. On the other hand, when it comes to confined (isolated) systems, the explosive effects can be attributed to pure thermochemical factors [48-55]. Thermal explosions occur when fast decomposition or runaway reactions cause the equipment to compress due to...
As a result, a physical (mechanical) explosion takes place, as shown in the right section of Figure 1. This type of explosion is typically characterized by the shell experiencing catastrophic failure, resulting in the release of fragments and a shock wave. The expansion of the pressurized gas generates a shock wave characterized by a brief duration and intense peak pressure. In this particular case, important considerations involve the shell’s pressure threshold and different decisions made in terms of design, such as the arrangement of safety valves. Additionally, RPT and BLEVE are closely linked to the excessive heating of liquids and the swift vaporization that can produce shock waves that propagate through the surrounding atmosphere. Ensuring the proper structural elements and design options are in place is of utmost importance to mitigate potential risks and enhance safety measures.

2. Accidental Explosions

Accidental/Unintentional explosions have emerged as an unfortunate consequence of mankind’s progress in technology. Initially, these explosions were primarily linked to the production, manipulation, and utilization of black powder. During the Middle Ages, alchemists unwittingly triggered explosions by unknowingly combining incompatible chemicals. The creation of a structured naming system for inorganic compounds by [35] paved the way for a prosperous era in preparative chemistry. This period witnessed the synthesis of numerous novel explosive substances and mixtures, consequently leading to an increase in laboratory-scale explosions. Subsequently, the advancement of high explosive technology gave rise to larger accidental explosions. During the same period, the advent of the industrial revolution brought about the utilization of fossil fuels, which in turn gave rise to coal mine explosions. Additionally, as the commercialization of grain handling and milling emerged in the 19th century, it also brought along numerous significant incidents of grain elevator and mill explosions. In more recent times, the development of large single-line petrochemical process units, as well as the transportation and storage of increasingly larger quantities of fuels at high pressure or low temperatures, has resulted in BLEVEs and unconfined vapor cloud explosions. The consequences of these types of explosions can be catastrophic, and their frequent occurrence in the past decade has prompted a renewed focus on researching the characteristics and dynamics of all types of explosions.

Explosion damage occurs due to various factors. The surrounding structure can disintegrate and serve as the main source of primary debris. Objects encountered by the blast wave can suffer damage, resulting in secondary fragments that may harm other objects (such as shards of glass from shattered windows). Combustion explosions can emit radiation, causing burns and igniting combustible materials even from a distance [33].

Assessing the impact of an explosion often involves evaluating the internal damage to the surrounding structure [28-33]. While quantifying this damage can be challenging, it provides valuable insights into the explosion’s progression. In the case of buildings, analyzing the displacement of objects such as walls, partitions, and furniture can help diagnose the...
direction and extent of the explosion. When it comes to metal vessels, the mode of rupture depends on factors such as the specific type of metal, its temperature, and the rate of internal pressure application. Additionally, studying the trajectories of primary fragments can offer valuable information about the forces at play during rupture. Previous research conducted by Baker and his colleagues in 1975 and 1978 demonstrated that while primary fragment patterns may not be entirely reproducible, they can still be reasonably predicted with a certain level of accuracy.

Fig. 3. Beirut explosion: satellite images before and after the blast (Source: Popular Mechanics; BBC News 2020)

Fig. 4. Depiction of the destruction resulting from the explosion in Beirut (Source: Popular Mechanics; BBC News)

When a blast wave travels through an open area, its interaction with various objects is quite complex. The blast wave possesses an extremely high energy density, which is released suddenly and rapidly. In order to prevent major industrial explosions, it is suggested to implement the following precautions:

1. Determine the maximum amount of explosive material that can be stored in a given location;
2. Construct a storage facility with sacrificial surrounding walls or barriers to absorb the blast energy;
3. If an explosive event occurs, notify emergency services immediately.

The explosion gives rise to a blast wave known as a free field blast wave until it encounters obstacles in its trajectory. Consequently, this phenomenon leads to the bending, buckling, tearing, or shattering of objects. When a blast wave travels through an open area, its interaction with various objects is quite complex. The blast wave possesses an extremely high energy density, which is released suddenly and rapidly. In order to prevent major industrial explosions, it is suggested to implement the following precautions:

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4. Deadly Explosion in Ghana As Motorbike Collides with Truck Transporting Explosive Material for Gold Mine (January 2022)

On January 20, 2022, a huge explosion took place at the Apeate Community, near Bogoso City which is about 180 miles from the west of Accra, the capital of Ghana (Ghana Explosion Report, 2022). The blast occurred due to a motorbike accidentally going under a truck that was carrying explosives for Chirano Gold Mines at Bogoso (Figure 5(a)). As soon as the explosion happened, the citizens of that region rushed to the blast scene and another blast took place within a few minutes (Ghana Explosion Report, 2022). The aftermath of these catastrophic blasts can be seen in Figure 5(b).

A total of 3,300 people had been affected by the incident, while the death of 17 people was confirmed and 59 people were seriously injured. The reports from the National Disaster Management Organization (NADMO) highlighted that...
least 500 buildings had been destroyed as a consequence of the blast event and ~1,500 people became homeless (Ghana Explosion Report, 2022). The blast also blew up major roads in that region and made ample commuters stranded for very long (Ghana Explosion Report, 2022). Such incidences, the corresponding civilian casualties, and the structural damages are unacceptable. Hence, effective measures that could mitigate such risks out of explosions are compellingly needed.

5. Global Terrorism Index (GTI): Measuring the Impact of Terrorism

The GTI is a thorough examination of the effects of terrorism or terrorist attacks, which includes 163 nations across the globe, and covers 99.7% of the world's population (Global Terrorism Index, 2022). The GTI assesses the level of property damage, economic encounters, deaths, and damages to infrastructure facilities that have been caused by a variety of variables. When assessing the global effect of terrorism, a five-year weighted average is utilized as the measurement period. The GTI report was compiled with the help of the Terrorism Tracker as well as other available sources. To determine a composite score by using the GTI, which enables us to produce a ranked order for the damage that terrorism has had on nations all around the globe. It assigns a number to each nation depending on the extent to which terrorism influences that nation's economy, with 0 indicating that there is no impact from terrorism and 10 indicating that there is the most demonstrable damage from terrorism. The rankings attained by each county in accordance with the GTI score are shown in Figure 6.

The GTI ratings for Afghanistan, Burkina Faso, Syria, Mali, Niger, and Mozambique in 2021 are higher than the ratings for those countries in 2017. On the other hand, the GTI ratings for Egypt, Pakistan, and Iraq in 2021 are lower (Figure 7). In addition, India, Somalia, and Cameroon have a little drop in the value of their GTI Score in 2021 as compared to the year 2017. The GTI rating of Myanmar is rapidly increasing in 2021 as compared to the year 2017. In view of the enormous investment that nations all over the governments in the world have made in the fight against terrorism, it is imperative that the data available now is to be compiled and analyzed to acquire a better understanding of the phenomenon. The only way to make headway against the worldwide menace is to proceed in this manner. The Global Trends Initiative intends to explore the aforementioned phenomena as one of the key foci of its work. This will contribute to a discussion that is both positive and grounded in reality about the trajectory of terrorism and the actions that the governments will have to take to combat it.

Fig. 7. GTI score rank, 2021 (Global Terrorism Index, 2022)
6. Blast Mitigation

- Creating barriers to increase the distance between structures and potential blast sources.
- Redistribution of structural mass to improve resistance to blast loads.
- Employing lightweight metallic and polymer foams on the surface of structures.
- Designing buildings with large rectangular cross-sections to minimize blast effects.
- Constructing sacrificial walls, shielding, and tensioning out of vehicle orifices.

6. Summary

- A concise overview of topics related to explosions, including accidental detonations, the impact of terrorist attacks, and solutions to blast mitigation.
- The article emphasizes the importance of analyzing structural response to extreme loading to enhance design.
- Further research is necessary to gain a deeper understanding of the relationship between blast hazards and structural integrity.
- Active and passive measures must be implemented to mitigate the impact of explosions on infrastructure and facilities.
- Structural resilience against explosions is crucial, and building orientation plays a significant role in blast mitigation.
- The findings of the Global Terrorism Report illustrate the increase in terrorist activity, with a focus on regions such as the Middle East, North Africa, and South Asia.
- Civilian casualties have also risen significantly in countries like Afghanistan, Burkina Faso, and Niger.
- The situation in seven of the ten countries most affected by terrorism in 2021 is deteriorating, highlighting the need for continued investment in blast mitigation strategies.

7. Blast Mitigation

- Active and passive measures are essential for enhancing structural integrity in the face of blast loading.
- Proper retrofitting techniques and the use of high-performance materials are necessary to mitigate the effects of explosions.
- The implementation of both active and passive measures is crucial for ensuring safety and durability in the design of blast-resistant structures.
- Blast-resistant buildings should be designed for continuity and the use of shock-absorbing materials.
- The importance of analyzing the orientation of buildings and the structural design in relation to blast hazards cannot be overstated.
- Effective blast mitigation strategies include creating barriers to increase the distance between structures and potential blast sources.
- Redistribution of structural mass is crucial for improving resistance to blast loads.
- Lightweight metallic and polymer foams can be applied to the surface of structures to enhance blast mitigation.
- Buildings should be designed with large rectangular cross-sections to reduce the impact of blast waves.
- Sacrificial walls, shielding, and tensioning techniques can be employed to mitigate the effects of explosions.

7. Summary

- The article provides a comprehensive exploration of blast mitigation techniques, emphasizing the importance of analyzing structural response to extreme loading.
- Active and passive measures must be integrated into building design to enhance structural integrity in the face of blast loading.
- Further research is necessary to gain a deeper understanding of the relationship between blast hazards and structural integrity.
- The implementation of both active and passive measures is crucial for ensuring safety and durability in the design of blast-resistant structures.
- Blast-resistant buildings should be designed for continuity and the use of shock-absorbing materials.
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