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The Influence of Impact and Explosion as Agents of Defects on the Structural Integrity of Buildings

Md Azree Othuman Mydin[1,*], Adi Irfan Che Ani[2,3], Nik Fatma Arisya Nik Yahya[4], Nafisah Ya'cob @ Ya'acob[5], Mohd Nasrun Mohd Nawi[6]

[1] School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia
[2] Department of Architecture and Built Environment, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM), 43600 UKM, Bangi, Selangor, Malaysia
[3] School of Liberal Studies (CITRA), Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia
[4] Faculty of Engineering and Quantity Surveying, INTI International University, 71800 Nilai, Negeri Sembilan, Malaysia
[5] Department of Quantity Surveying, Faculty of Built Environment, Tunku Abdul Rahman University of Management and Technology, 53300 Setapak, Kuala Lumpur, Malaysia
[6] School of Technology Management and Logistics, Universiti Utara Malaysia, Kedah, Sintok, 06010, Malaysia

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ABSTRACT

Deficiencies in the structure of buildings have detrimental effects on occupants, both in the immediate and extended periods. This includes both anomalies that are inherited from the father and those that occur in siblings. Building faults can have a detrimental impact on the construction, functionality, and visual appeal of the building. From minor functional deficiencies to significant flaws that might ultimately lead to the structural failure of a building, encompassing problems relating to design, functionality, and even the general durability of the construction. A flawless framework is crucial for ensuring usability and safety. Buildings that are structurally deficient pose risks to the safety and well-being of the people inside. There are multiple classifications of defects. Several factors, including water, shifting soil, weather, chemical reactions, vibrations, impacts, explosions, loads, insects, and natural decay, can result in building imperfections. This study investigated the structural deficiencies in the structure resulting from impact and explosion. It aimed to determine the exact cause of each flaw and its vulnerabilities, analyse the roots of these problems, and propose realistic methods to rectify them. Additionally, it will address the diagnostic instruments that can be employed to detect these flaws, present a systematic approach for assessing the flaws, and suggest a course of action to avoid like flaws in the future. Two case studies are being undertaken for the purpose of observation in the study. The findings of this study can provide guidance to Building Surveyors and Structural Engineers in conducting thorough building condition assessments specifically for problems caused by impact and explosion.

* *Corresponding author.*
E-mail address: azree@usm.my

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1. Introduction

Structural flaws in buildings have a negative impact on users both in the short and long run. This encompasses both paternal and lateral abnormalities [1]. Building faults can have a detrimental impact on the construction, functionality, and visual appeal of the building [2]. From minor functional failures to large faults that can ultimately result in the breakdown of a building, including issues related to design, functionality, and even the overall lifespan of the structure. An impeccable structure is of utmost significance for the purposes of usability and safety [3]. Structurally compromised buildings provide hazards to occupants regarding their safety and well-being. There exist numerous categories of faults [4]. Building flaws can occur due to several factors and are produced by specific agents such as water, soil displacement, climatic conditions, chemical reactions, vibrations, impacts and explosions, loads, insects, and normal wear and tear [5].

A building impact and explosion refers to a situation in which a building sustains significant damage due to a powerful impact or force, resulting in a deadly explosion and extensive destruction [6]. This tragedy is attributed to multiple factors, encompassing accidents, natural disasters, and even acts of violence. Building impacts typically result from accidents with automobiles, corrosive items, projectiles, or debris [7]. The consequences of this will result in structural damage to the building, leading to its collapse and destruction. Figure 1 shows the building being consumed and the effects of shock wave growth.

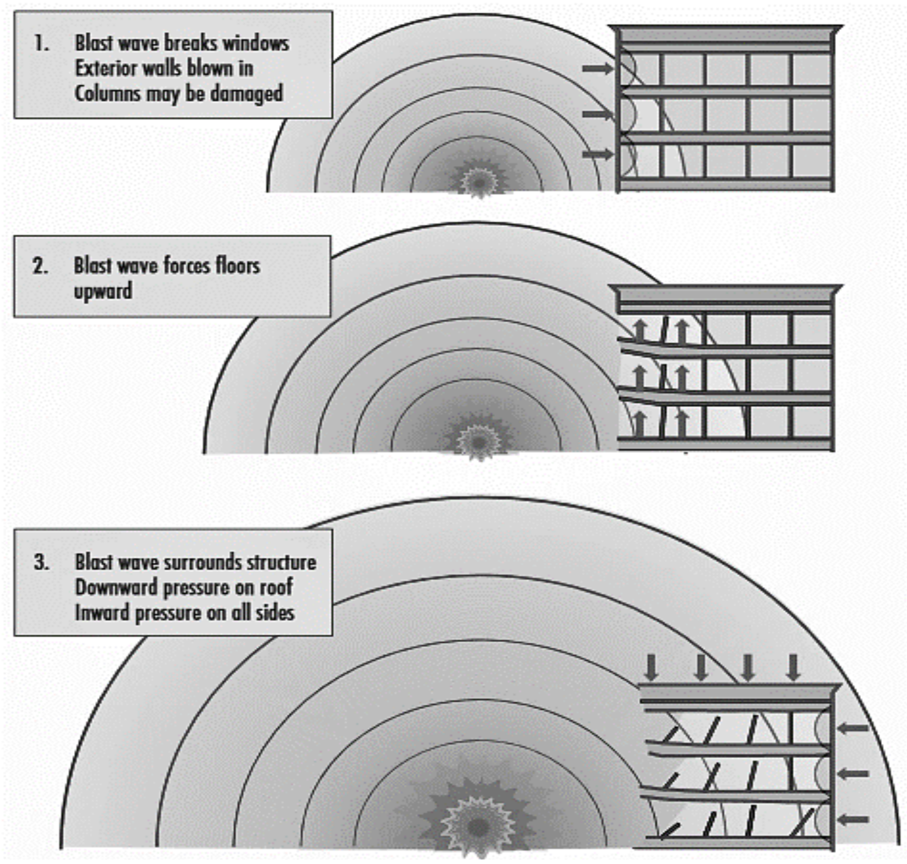


Fig. 1. Chronological progression of air-blast phenomena

The design often involves using explosive forces that are significantly higher than the other loads taken into account. However, they undergo swift breakdown in both space and time. Typically, the pressures that are produced rise in a straight line as the deterrent's size, increases, and decline rapidly as the gap away from the blast upsurges as demonstrated in Figure 2. The blast has a very brief time frame, characterized by milliseconds or thousandths of a second as been illustrated in Figure 3.

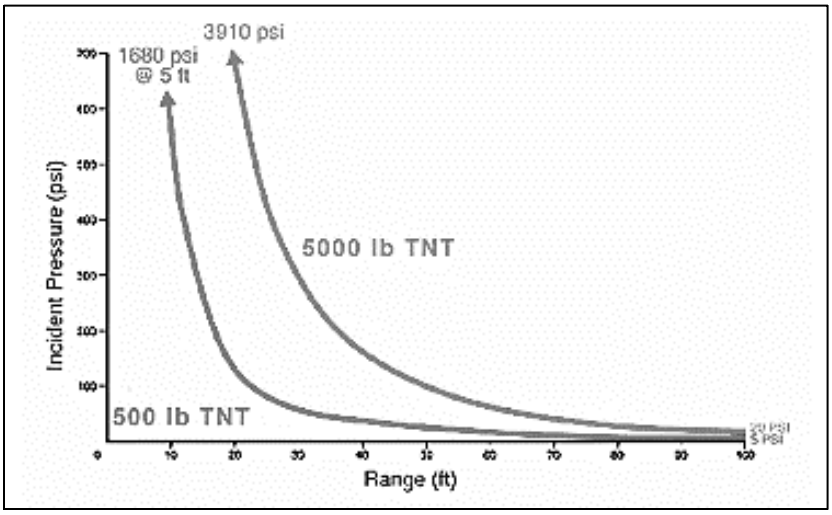


Fig. 2. The relationship between air-blast pressures and the size and detachment of a weapon

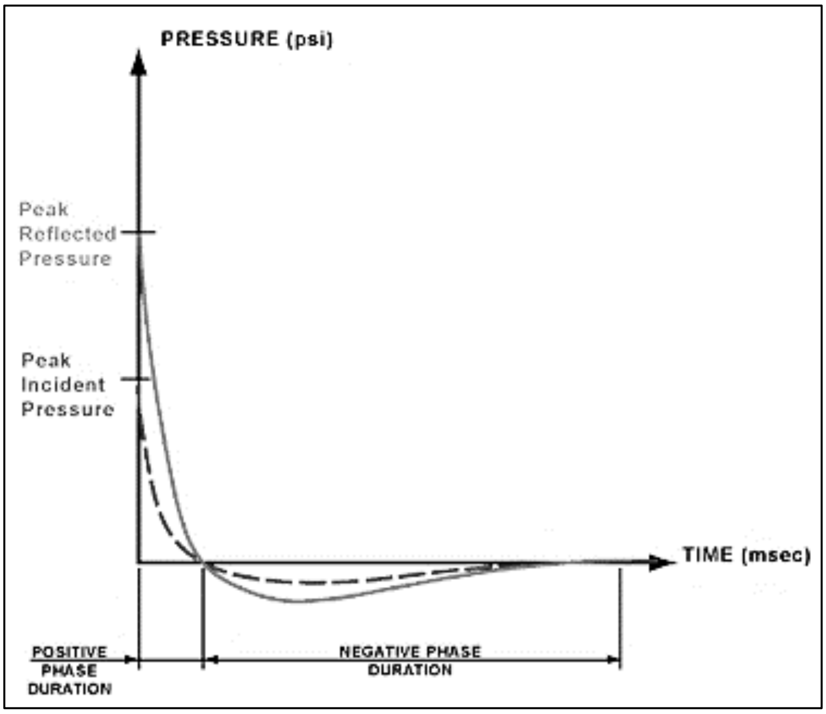


Fig. 3. The variation of air pressure over time

An explosion is a type of event that occurs when a significant amount of energy is rapidly released in the form of a powerful wave, which includes explosion, heat, and pressure. This explosion was caused by a combination of circumstances such as gas leaking, chemical reaction, or intentional aggression [8]. An explosion occurring within a building will result in significant harm to the building, ultimately resulting in the complete destruction and collapse of its structural integrity. Not only would this impact the targeted building, but it will also affect the surrounding infrastructure, resulting in significant destruction and even loss of life. Both flaws result in significant harm and devastation to buildings and even human lives [9]. The destruction caused by disasters not only results in the loss of buildings and property, but also leads to significant loss of life [10].

There are other concerns related to this flaw, such as the incident reported by BERNAMA in 2024 involving the gas explosion at the Puchong factory. This explosion resulted in the death of two individuals and caused injuries to two others. Based on the press report, the occurrence can be attributed to a gas explosion that occurred at the business. The explosion occurred in the facility and was caused by the ignition of acetylene gas [11]. "Ventilation measures are currently being carried out to eliminate the gas present within the building," stated Ahmad Mukhlis Mukhtar, assistant director of the operations section at the Selangor Fire and Rescue Department.

In October 2023, The Malaysian Reserve reported a modest explosion at Menara Lembaga Pertubuhan Peladang (LPP) near Bukit Tunku. The explosion occurred in a low-voltage chamber located in basement 1. The commander verified the presence of a crater measuring two feet in width as a consequence of the explosion, and there have been no recorded instances of injuries. The spokesperson of The Kuala Lumpur Fire and Rescue Department (JBPMKL) stated that the explosion was a result of an underground wire fire. However, in April 2024, FMT Reports released news regarding the occurrence of damage and an explosion in Petaling Jaya as a result of rock blasting work [12]. The lack of uniformity in one of the massive stone blocks was due to a fault line, which resulted in the presence of small air pockets that were not evident on the surface. These microscopic cavities resulted in the explosives generating sound and pressure that exceeded estimates [13]. "The soil, utilised as a protective material, detonated and dispersed beyond the anticipated range," stated the individual responsible for overseeing the building site.

This study investigated the structural deficiencies in the structure resulting from impact and explosion. It aimed to determine the exact cause of each flaw and its possible vulnerabilities, analyze the origins of these flaws, and propose realistic remedies to rectify them. It will also discuss the diagnostic tools that can be used to identify these defects, provide a step-by-step procedure for evaluating the defects, and propose an action plan to prevent similar defects in the future. Two case studies are being conducted in for the purpose of observation in the study.

2. Methodology

The methodology for conducting observations and literature surveys regarding building crack as well as site visits involves a methodical strategy to collect extensive data and gain valuable insights. The observational part is conducting on-site visits to different structures exhibiting cracks, meticulously recording their structural states, and classifying the cracks according to their specific attributes, such as size, position, and patterns. Using instruments such as measuring tapes, cameras, and crack gauges can assist in precise data gathering. In addition, performing on-site interviews with building owners, maintenance people, or structural engineers can offer useful contextual information regarding the history, causes, and potential consequences of the detected fractures. The observational phase is essential for gaining a fundamental comprehension of the actual occurrences of construction cracks.

The literature review component entails a thorough investigation of academic journals, research papers, industry reports, and pertinent publications related to building cracking, structural engineering, materials science, and construction techniques. The primary objective is to find and analyse established theories, models, case studies, and best practices concerning crack development, processes of progression, risk assessment, and techniques for mitigating the risks associated with cracks. By conducting keyword searches, tracking citations, and querying databases, one can acquire a thorough comprehension of the theoretical foundations and practical consequences of constructing fractures. By combining the information gathered from the literature study with the observational data, a more detailed understanding of the observed events can be achieved. This allows for the development of suggestions for crack prevention and remediation procedures that are founded on solid evidence.

Finally, the process of combining the observational findings with the knowledge obtained from the literature study requires doing a thorough analysis to uncover similarities, differences, and developing trends. The utilisation of several data sources in this triangulation process improves the accuracy and dependability of the research results, enabling a more comprehensive comprehension of the aspects that contribute to the occurrence of building fractures. In addition, the utilisation of qualitative and quantitative analytical methods, such as theme analysis or statistical modelling, can aid in the identification of correlations, trends, and probable causative links between different elements and instances of crack occurrences. The iterative nature of this procedure enables the improvement of hypotheses, verification of findings, and generation of new research inquiries to enhance the comprehension of building fracture phenomena and facilitate evidence-based decision-making in the field of structural engineering and construction practices.

3. Specific Agent of Defect and Its Potential Flaws

3.1 Agent of Defect

3.1.1 Impact

When two objects collide, they exert force on each other, resulting in a collision. Multiple outcomes can arise from this interaction, such as deformation, fracture, or rebound [14]. There are four types of impacts: direct impact, which occurs when two objects collide head-on; side impact, which occurs when two objects collide from the side; penetrating impact, which occurs when one object pierces another object; and explosive impact, which occurs when two objects collide with great force and result in an explosion [15]. Engineers can enhance the ability of equipment and structures to withstand impact by utilizing durable materials and innovative design.

3.1.2 Explosion

An explosion occurs when the stored energy of a substance is suddenly released, resulting in a powerful surge of pressure and heat wave [16]. Defect agents refer to factors that can heighten the probability or intensity of explosions. Chemical instability is a factor that can lead to sudden and explosive reactions in compounds [17]. Explosions can occur when containers holding explosive substances develop structural defects or fissures, allowing pressure to accumulate [18]. These imperfections may deteriorate as a result of external factors such as elevated pressure or temperatures. Explosions can also occur due to human error, such as mishandling or improper storage of explosives. External forces, such as impact or friction, can initiate chemical processes that may lead to explosions [19]. In order to ensure safety and prevent explosions, it is crucial to have a thorough understanding of and effectively handle the potential causes of defects while dealing with explosive materials.

3.2 Potential Flaw

3.2.1 Human error

Human error can be seen as imperfections when there are problems in buildings. The occurrence of mistakes may be attributed to human error rather than mechanical malfunction. Typically, this occurs in the construction phase [20]. The building has been inadequately constructed at this time, which will compromise its structural integrity in the future [21]. Building flaws in the future can be attributed to human error and the absence of project auditing, as depicted in Figure 4. After the construction of a building, contractors and developers must conduct a final inspection to verify its safety for potential buyers or renters [22]. If the building and infrastructure are not thoroughly examined or can be negligently neglected, even a minor mistake or error in the construction could potentially lead to future structural cracks or other issues. Figure 5 exhibits evident fractures in the highway structure. Furthermore, Construction errors, whether due to design or craftsmanship flaws, can lead to structural fissures. Inadequately executed connections, inadequate structural reinforcement, or material defects can undermine the stability of a building. Figure 6 depicts the structural fissures that emerged in the flat residential area.

Fig. 4. Major cracks due to lack of project auditing

Fig. 5. Visible cracks highway structure

Fig. 6. Structural cracks occur at flat residential

3.2.2 Environmental factor

Environmental conditions greatly influence the development and consequences of potential defects, such as cracks, and their relationship to accidents or collisions. Various elements, including as fluctuations in temperature, levels of humidity, presence of corrosive compounds, and occurrences of natural phenomena like earthquakes (Figure 7), can contribute to the formation and spread of defects in materials and structures (Figure 8). Moreover, severe weather conditions can worsen the susceptibility of structures with preexisting defects, hence heightening the likelihood of harm or collapse in the event of crashes or collisions. For instance, the presence of fractures in a building's foundation can be quite worrisome since they may indicate structural issues that pose a threat to the stability and safety of the building [23]. Foundation cracks are a common phenomenon caused by the frequent changes in climatic conditions, which lead to the expansion and contraction of the soil and structure components [24]. The durability and structural soundness of a structure rely on insight into the root causes of foundation cracking and being able to identify these issues [25].

Fig. 7. Structural damage due to earthquake

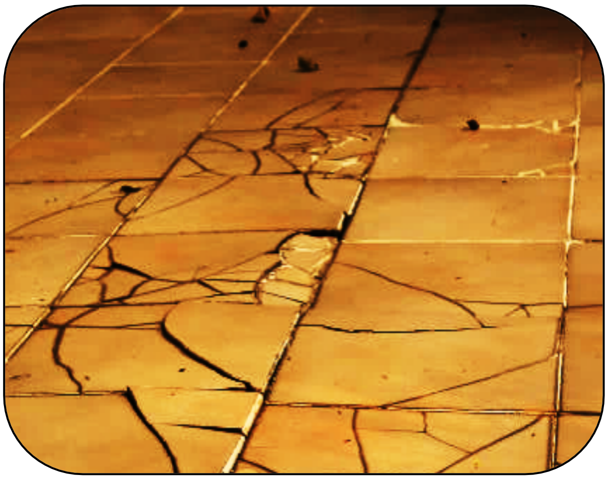


Fig. 8. Post-earthquake floor cracks

3.3.3 Structural weaknesses

Structural vulnerabilities in buildings can arise from multiple factors, each impacting the stability and safety of the structure, as depicted in Figure 9. Design problems arise from errors or oversights in the planning stage, resulting in structural parts being improperly positioned or unable to withstand environmental forces such as earthquakes. Inadequate construction quality, frequently resulting from the utilization of substandard materials or negligence towards building regulations, can undermine the structural soundness of a structure [26]. Figure 10 clearly shows concrete spalling occurring at the wall section of the building. The structural components of materials deteriorate over time owing to weathering, moisture, or chemical reactions. Additionally, natural calamities like earthquakes or floods can cause significant damage. Failure to regularly maintain and repair the structure worsens existing flaws, leading to a gradual weakening of the structure. In order to maintain the safety and stability of structures, it is imperative to address these problems by implementing meticulous planning, ensuring high-quality construction, conducting regular maintenance, and strictly adhering to safety requirements [27].

Fig. 9. Structural degradation impacting the stability and security

Fig. 10. Indication of concrete spalling observed on the wall

3.3.4 Chemical instabilities

Chemical instabilities introduce unpredictability and hazards to various systems and processes, thereby making them possible sources of errors (Figure 11). Envision the amalgamation of chemicals resulting in an unexpected ignition or the emission of hazardous vapors instead of the predicted response. The inherent unpredictability of this phenomenon might lead to accidents, fatalities, or damage to property. These instabilities are especially detrimental as they can be initiated by extremely little alterations in handling or temperature [28]. Moreover, these instabilities possess the capacity to gradually wear away materials or pollute the atmosphere, water, and land, so causing harm to the ecosystem. Adherence to stringent rules and safety protocols is necessary while dealing with, storing, and producing chemicals in order to mitigate these hazards [29]. In light of all factors, it is crucial to appreciate and address chemical instabilities in order to ensure safety and reliability across various sectors and applications. Figure 12 depicts an instance of corrosion in steel bars beneath the flooring system, resulting in a subsequent effect on the stability of the building.

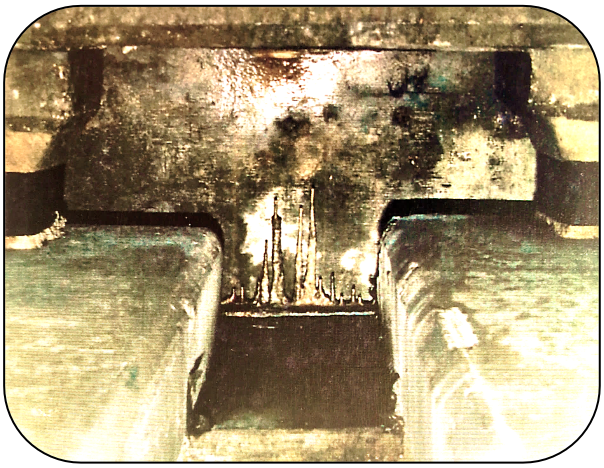


Fig. 11. Chemical deterioration mechanism

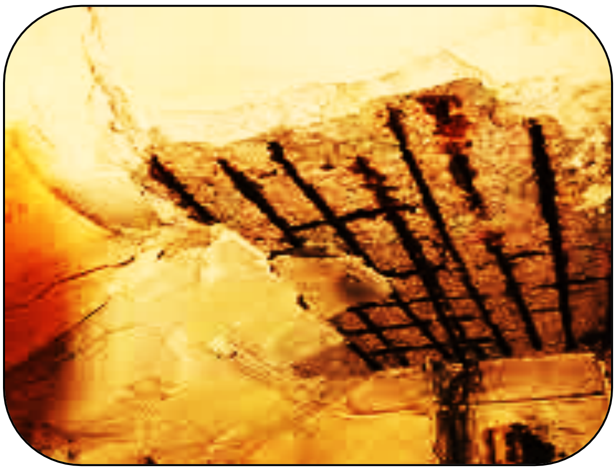


Fig. 12. Corrosion of steel bars beneath the flooring system

4. Origins of Defects and Practical Corrective Measures

4.1 Common Origins of Defects

4.1.1 Accidents

An accident refers to an unplanned event that occurs and results in damage, injury, danger, and loss. Construction accidents will affect buildings and even explosions. This accident occurs in various situations. Among them are human error, equipment malfunction, etc. In addition, the crash of a vehicle into the level of a building, a broken channel, and a gas tank is also an accident that can result in an explosion. accidents result in negative consequences, such as injury to personnel, damage to property, or harm to the environment [30].

4.1.2 Natural disasters

Building impact and explosion from natural disasters cannot be avoided anymore. However, some steps can be taken to reduce the building's impact [31]. These natural disasters include flash floods and typhoons that often occur on the East Coast of Malaysia. Structural damage from this incident will cause malfunction, cause building impact and then lead to an explosion problem [32].

4.1.3 Gas leaking

Gas leaking is a crucial part of building explosions. This is because of the nature of the gas which spreads very quickly and spreads causing the duration of the explosion to be very short and can cause a very devastating explosion [33]. These leaks are caused by leaky pipelines, faulty equipment, and even improper installation causing gas to accumulate in a space and will cause very quick and severe destruction [34].

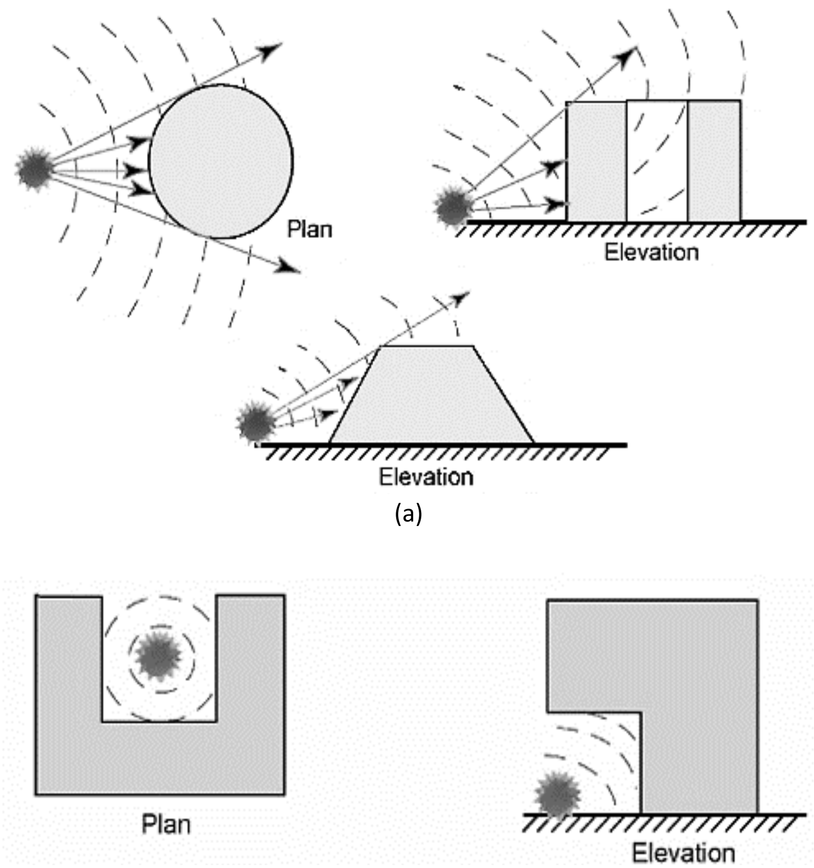
4.1.4 Chemical accident

The handling of chemicals that do not follow the procedure will cause a building impact and explosion that is very devastating. This is because chemicals are very sensitive substances and require careful care and handling [35]. Chemicals are very dangerous substances. It needs to be handled by experts and follow the correct protocol, otherwise danger and destruction will occur. This will not only cause the loss of the building structure, but it will also threaten property and most importantly it will take lives [36].

4.2 Practical Corrective Measures

4.2.1 Placement of buildings

The positioning of the structure on its location might significantly influence its susceptibility. Optimally, the building is situated at a considerable distance from the boundaries of the property. This applies not just to the boundaries adjacent to streets, but also to the boundaries adjacent to neighboring properties, as it is uncertain who will occupy these properties in the future over the duration of the building. An illustrative instance of this is to construct a spacious plaza in front of the building, while allocating minimal space for setbacks on the sides and rear of the building. It should be noted that this approach typically heightens the susceptibility of the remaining three sides. Furthermore, if this method is employed, the outer covering may protrude over the underlying structure underneath the surface, necessitating its inclusion in the overall protection design endeavor. The configuration of the structures can have a significant impact on the total extent of damage to the structure as shown in Figure 13. Reentrant angles and extends have a high probability of trapping the vibration, potentially intensifying the impact of the air-blast. It is important to ponder that big or progressive reentrant angles have a less impact compared to small or abrupt reentrant angles and extensions. Typically, it is preferable to have convex curves rather than flat designs for the outside of the structure. The degradation of reflecting impact on the exterior of a circular structure is quicker compared to that on a flat or "U" oriented structure. Terraces that are considered as roof schemes that are exposed to descending loads necessitate meticulous construction and detailing to minimize potential structural harm to underlying beams.



(b)

Fig. 13. Influence of building shape on air-blast loading (a) Shapes that dissipate air blast (b) Shapes that accentuate air blast

4.2.1 Safety inspection and maintenance

Regular safety inspection and maintenance of buildings is very important for the occupant and even for the public. This is to ensure that every part and everything is safe for everyone. It also will reduce the damage that can cause an impact and explosion before it starts or before it gets worse. Any problem can be cured in the early stage. It also includes the material usage and the construction technique that enhances the building's resistance to external forces [37].

4.2.2 Public awareness and training

Early education to the public is very important for awareness of any accidents that have happened and are about to happen [38]. This is so that the public can take precautions and also know the safe measures in case something unwanted happens. The public needs to know the potential risks and safety protocols to promote awareness and preparedness in the event of an emergency or accident.

4.2.3 Regulatory compliance

It is very important to ensure that the building that will be built and that has been built complies with the building code, safety regulations, and industry standards to avoid the occurrence of an unwanted incident. Building safety starts with very strict compliance with legislation. This will help all parties to always be in a safe condition by complying with all the standards that have been set. Regulatory compliance can reduce the possibility of building effects and explosions if all regulations are followed perfectly [39].

4.2.4 Emergency response planning

All parties need to be quick in responding to emergencies. This is to maintain the safety of residents and users around the building. This includes establishing evacuation procedures, designated muster points, and effective communication protocols [40]. Fast response and response will reduce the amount of loss and loss of life and property if any serious accident such as building impact and building explosion. Elements of emergency response planning are prevention, mitigation, recovery, response and preparedness as shown in Figure 14.

Fig. 14. Components of emergency response planning

5. Propose Action Plan for Defects Avoidance

5.1 Risk Assessment and Analysis

Risk assessment involves looking ahead to anticipate potential problems and their severity. It helps identify possible dangers in a situation or environment, determining their likelihood and impact. Understanding these risks enables us to take preventative measures or reduce their severity. This could involve implementing safety protocols, using specialized equipment, or modifying procedures. Risk assessment also ensures compliance with regulations and standards while optimizing resource allocation. Ultimately, its goal is to maintain safety and minimize harm by making informed decisions and taking appropriate actions [41]. Figure 15 shows the risk analysis framework.

Fig. 15. Risk analysis framework

5.2 Quality Control and Compliance

Integrating quality control and compliance procedures is crucial to an active defect avoidance plan to detect, stop, and handle faults at every stage of the product lifecycle. This entails carrying out routine audits to guarantee compliance with laws and standards, putting quality control checks into place at crucial points in the manufacturing or implementation process, and continuously enhancing procedures considering user feedback and lessons gained. Organizations can improve product reliability, customer satisfaction, and overall business performance while lowering the risk of defects and related costs by placing a high priority on quality and compliance. Organizations can prevent flaws from making it into the final product or system by identifying and addressing concerns early in the production or implementation process using strong quality control measures. Comparably, compliance refers to following the rules, laws, and regulations that apply to a specific business or activity. It guarantees that activities, procedures, and goods fulfill performance, quality, and safety requirements set forth by industry best practices or regulatory bodies [42].

5.3 Proactive Maintenance and Inspection

An active plan for defect avoidance must include proactive maintenance and inspection, which concentrate on seeing and fixing problems before they become more expensive ones. To avert any flaws or breakdowns, proactive maintenance entails planned inspections, repairs, and upkeep of machinery, infrastructure, and equipment. Organizations can identify early indicators of wear, damage, or malfunction and take corrective action to prevent more serious problems later by routinely monitoring and servicing assets [43]. Proactive inspections, on the other hand, entail methodical evaluations of buildings, structures, and systems to spot any weaknesses or openings that can result in problems or safety risks. Organizations can increase asset lifespan, reduce maintenance costs and downtime, and improve dependability by doing routine inspections and taking preventative action based on the results. All things considered, proactive maintenance and inspection are crucial tactics for preserving operational effectiveness, guaranteeing safety, and stopping flaws from impairing output or creating interruptions.

5.4 Material Selection and Durability

An active plan for defect avoidance should prioritize material selection and durability, with an emphasis on selecting materials that can endure use demands and environmental stressors while minimizing the possibility of faults and failures [44, 45]. The process of selecting materials entails determining which ones are suitable for the intended use and surroundings, keeping in mind attributes like durability, strength, and resistance to corrosion [46, 47]. Organizations can lessen the possibility of problems linked to material deterioration or insufficiency by using premium materials that are appropriate for the requirements of the project [48]. The capacity of a material to tolerate weathering, wear, and other types of degradation over time is referred to as durability [49]. When it comes to defect avoidance, durability comes first since it guarantees that materials will be able to retain their structural integrity and performance traits for the duration of their anticipated lifespan [50, 51]. This entails considering elements including fatigue, abrasion resistance, corrosion resistance, and environmental exposure [52].

Subsequently, organizations may reduce the likelihood of faults and failures resulting from material deterioration, subpar performance, or environmental causes by prioritizing the selection and durability of their materials [53, 54]. This entails using materials whose longevity and performance have been demonstrated, testing, and evaluating them to see whether they are appropriate for the intended use and adding safeguards to increase longevity and durability [55, 56]. In the end, dependability, safety, and longevity are ensured while reducing the need for expensive repairs [57] or replacements by choosing suitable and robust materials [58] that can survive the rigors environment. Additionally, it is proposed to employ lightweight materials that may resist impact and explosion [58, 59]. There are several lightweight concretes such as lightweight aggregate concrete, lightweight foamed concrete and autoclaved aerated concrete [60-63]. Lightweight concretes possess a lower elastic modulus compared to standard weight concrete but have similar strength [64]. Nevertheless, when accounting for the deflection of a slab or beam, the decreased self-weight of lightweight concretes serves to offset this disparity [65].

6. Conclusions

Impact and explosion events can pose significant risks to buildings and structures, necessitating tailored corrective measures for mitigation. Structural reinforcement, regular safety inspections, emergency response planning, and security measures are practical steps to enhance resilience and prepare for emergencies. Diagnostic tools like crack gauges, moisture meters, and thermal imaging cameras aid in identifying and addressing building defects. The step-by-step defect evaluation procedure involves thorough preparation, visual inspection, measurement, documentation, analysis, and reporting. In an active defect avoidance plan, risk assessment, quality control, proactive maintenance, and material durability are key strategies to mitigate risks and ensure building integrity and safety.

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