Evaluation and Possibility of Rehabilitation of Damaged War Buildings in Benghazi

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ABSTRACT

This study aimed at assessing the war-damaged buildings in Benghazi and the possibility of rehabilitation by visualizing and modeling of damaged buildings in according to international codes and to further bringing this evaluation into analysis to establish knowledge that will help to understand the behaviors of damaged buildings and to decide whether they are capable for reconstruction or not.

To achieve this aim, certain models have been evaluated by either visual inspection or modeling evaluations by using one of the structural analysis programs after measuring and defining the structural properties.

This research study concluded with a set of conclusions and recommendations based on the evaluation study and the different case studies that represented a basis for preparing a strategy for reconstruction and enhancing the evaluation and rehabilitation strategies based on these recommendations.

Keywords: Structural Evaluation, Damage Evaluation, Existing Structures, Damaged War Buildings, Rehabilitation.

ÖZ

Bu çalışma, Bingazi'deki savaşta hasar gören binaların değerlendirilmesini ve rehabilitasyon olasılığını tartışmaktadır.

Bu çalışmanın temel amacı, hasarlı binaların uluslararası kodlara göre değerlendirilmesine ışık tutmak ve hasarlı binaların davranışlarını anlamamıza ve yeniden inşa edilebilir olup olmadığına karar vermemize yardımcı olacak bilgileri oluşturmaktır.

Bu amaçlara ulaşmak için, yapısal özelliklerin ölçülüp tanımlanmasının ardından yapısal analiz programlarından biri kullanılarak görsel inceleme ve detaylı inceleme yoluyla veya bu modellerden biri kullanılarak belirli modeller değerlendirilmiştir.

Bu çalışma, değerlendirme çalışmasına ve bu tavsiyelere dayalı olarak değerlendirme ve rehabilitasyon stratejilerinin yeniden yapılandırılması ve iyileştirilmesi için bir temel oluşturan farklı vaka çalışmalarına dayanan bir dizi sonuç ve öneri ile sonuçlanmıştır.

Anahtar kelimeler: Yapısal Değerlendirme, Mevcut Yapılar, Hasarlı Yapılar, Hasarlı Savaş Binaları, Rehabilitasyon.

DEDICATION

I am grateful to the God for the good health and wellbeing that were necessary to complete this thesis

I dedicate my dissertation work to my family and many friends.

A special feeling of gratitude to my loving parents,

Salema** and **Beleid

for their endless support and words of encouragement and push for tenacity.

*My sisters **Aisha** and **Rayan** my brother **Mohammed** and my future wife **"H"** have never left my side and they are very special.*

I also dedicate this dissertation to my many friends and family who have supported me throughout the process.

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I dedicate this work and give special thanks to my city Benghazi and my country Libya

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INTRODUCTION

1.1 Introduction

This research study discusses the post-war reconstruction and disaster recovery approaches to be followed, because of its particular significance at national and humanitarian level, where it introduces theoretical principles of restoration and deals with a collection of global and local experience in this area.

The main objective of the study is to analyze and review the reconstruction approaches around the world, to present them, try to apply them in Libya and test them by contrasting them with the experiences of other countries and to refer to the theoretical context for the implementation of an integrated strategy for reconstruction in Libya, and to implement a thorough reconstruction mission leading to better outcomes for Libya and the Libyans. In order to achieve these goals, several theoretical principles related to restoration have been examined after wars and disasters, in addition to reviewing the experiences in this field, and focused mainly on the methods for assessing and evaluating facilities and infrastructure, examining them and studying how to repair or reconstruct them.

Evaluating the existing reinforced concrete structures is a necessary and significant process for the engineers due to existing structures and buildings, as reinforced concrete has become a global construction material during the past decades up to present. There are many of the existing facilities need to either be rehabilitated or removed due to natural factors or manmade ones. Natural disasters, earthquakes, wars, conflicts, and other causes and factors sudden results in various degrees of damage. While it leads to the long abundance of these facilities and periodic maintenance, misuse, etc. ... to the deterioration of the condition of these installations over time.

In these days we see many critical factors and causes from human made by the wars and conflicts and here I focused on the evaluation of engineering facilities subject to disaster unexpected emergency (explosions) whereas the explosions and shells have enormous destructive effects on the structural elements in the buildings when a building is damaged in an explosion, it is necessary to know a set of basic principles in terms of entering the building, describing it, and knowing the facts from the antiquities and evidence at the site of the accident.

In Libya the war caused a huge destruction in many cities, a large number are gone among the vital installations, some of which have been partly and completely destroyed, In my pursuit of a reconstruction stage I had to work on my research to find a several ways for evaluating the damaged installations and find out the possibility of repairing and maintaining by methods of exploring the damaged structures, their entry and the methods of optimization and maintenance for them.

The removal of all installations that do not meet the requirements of the present day in terms of loading levels or that showing signs of damages is impossible practically and economically, so an operation must be performed technical, structural and economic evaluation of these facilities, to choose the decision and the best course of action in terms of restoration or consolidation for rehabilitation or removal, in order to continue to invest these facilities safely and economically.

The process of structural evaluation of existing facilities can be classified in two ways:

1- Visual inspection and examination by using simple and non-destructive measuring tools, and determining shapes types and severity of the damage formed in the structural elements of the structure, and then assessing the level of damage based on it from this information and data. As many references and researches have adopted this method it laid the foundations and principles for its use and application.
2- Modeling the structure by using one of the structural analysis programs after measuring and defining the structural properties of the actual structural elements of dimensions, resistance, etc., and in this study modeling method was adopted for one damaged building in Benghazi.

1.2 Statement of the Problem

The assessment process of the existing damaged reinforced concrete structures requires knowledge and huge amount of data. It is significant to take note of the condition of these facilities and this is by focusing on the assessment of the structural elements, whereas each element of the structure displays a signs and effects of various sabotage and damage with different indications as to their position and scale, and therefore take note of all the data and required information for the assessment process is complicated and error-proof by the engineers or technician. It takes a lot of time and energy to assess. Furthermore, the assessment process and the analysis of detailed findings for the whole system can also be subject, as well as the process of repairing and rebuilding the structure after its evaluation, it is significant to identify the strategies for immediate changes that would maintain the foundation of the facility and then continue with clear maintenance of the facility and reconstruction.

1.3 Aims and Objectives

The purpose of this study is to review the assessment and repair studies of the concrete structures damaged by the war, to derive the basic rules and criteria for the assessment and reconstruction process and then construct a full database that meets and complies with all the standards and global codes and sets out the rules, conditions and requirements for the process of restoring the damaged concrete structures in Benghazi.

Creating a full database for the technical evaluation of the damaged concrete structures from the international codes and finding methods for reconstruction and repair from previous studies and experiences, would contribute to the implementation of the reconstruction program in Benghazi.

1.4 Research Questions

What are the best evaluation methods for war damaged buildings in Benghazi?

If repair is possible after the evaluation prosses, what are the best repair technics?

1.5 Thesis Overview

In chapter one: Thesis introduction represents statement of the problem, aim and objectives of the study and research questions.

In chapter two: literature review represents the evaluation processes in several international codes.

In chapter three: The standards of technical evaluation processes for existing buildings took a place represents five adopted classifications of the existing structural elements conditions.

In chapter four: Assessment blast damage introduces the destructive factors of the blast and evaluating the structural elements deformation due to blast load pressure.

In chapter five: Rehabilitation and strengthening studying of the repair technics by representing a several repair procedures on damaged structural elements.

In chapter six: Case study evaluating a damaged war building in Benghazi by visual and modeling evaluation and studying the possibility of rehabilitation.

In chapter seven: Conclusion of the study.

Chapter 2

LITERATURE REVIEW

2.1 Evaluation Processes

Over time, engineering structures are exposed to a number of factors that affect them during their investment period, which contribute to the degradation of the bearing capacity of the elements by affecting the construction materials and the supporting structures of those structures. Where these effects occur in the structures in the form of cracks and fractures, in addition to the appearance of the element's shapes with different dimensions, which range from unnoticeable fractures to the occurrence of visible deformities and collapse of other components.

Due to the significance of the technical and structural evaluation process of the existing facilities, many have been developed the global requirements and codes for organizing the evaluation process and establishing foundations, principles and marginal values permissible damages that may occur in these facilities.

Safety acceptance criteria for facilities based on existing guidelines and methodologies should be based. Therefore, safety acceptance limits must be calculated (implicitly or explicitly) according to the probability of failure, potential loss, amount of investment or budget needed to improve safety, and possibly a combination of all of these factors. It has developed such goals for various industrial activities including new civil engineering facilities (Diamantidis & Bazzurro, 2007).

The current approaches of establishing acceptance limits for new facilities (Diamantidis & Bazzurro, 2007) include:

- Conclusions from disaster and conflict rates, observed and documented economic losses.
- Calibrate the current experience based on the assumption that the margin of safety provided by the current experience is acceptable and economically optimal. And It should be noted that, according to non-technical terminology, commonly, the security term here is a property that exposes the investors of origin to acceptable risks without limit injury or death.
- Take a decision based on the amount of public interest and the amount of the material cost, expected failure and collapse (such as structural damage, loss of ability to do the job).

Through the border standardization process and the established standards by common law, building codes have their roots and foundations in resulting criteria from failure statistics, and they have been calibrated to represent the available experiences contain the elements of costing analysis and general benefits, so the standard approach It is just a derivation from the first three approaches.

These current standards for public structures risks that are discussed by (Diamantidis & Bazzurro, 2007) depending on:

1- Experience gained from European practice and codes.
2- Review the current standards for structures in the seismic regions of America.
3- Industrial experience gained from various projects.
4- Recommendations made by the Joint Committee on Construction Safety (JCSS).

5- Studying of costs and benefits, including costs of avoiding the disasters.

The limits of maintenance acceptance depend on the structural characteristics and details on the economic standards (Vrouwenvelder, 1997) represented by:

- The marginal cost of reliability (Δcost / Δrisk)
- The consequences of failure.

The consequences of failure include direct material losses to repair the damage, to demolish and reconstruction, and also for so-called intangible losses such as the loss of future opportunities, as well as losing in general welfare and the profession's reputation. In general, the goals may be different for different stakeholders (Landlords, Tenants, Investors, Developers, and the public ...) given that each party has its different priorities.

The safety assessment of the existing structures is different depending on the type of structure and the reason of the assessment. In the areas with high seismic risk, available codes such as (ASCE, 2017; FEMA, 2018) and (ATC 1996) provide concepts of seismic evaluation of existing structures and the performance of these structures is evaluated in terms of financial and human losses and the period of structure suspension.

Furthermore , safety standards have been established for existing structure in the international codes and recommendations, such as American Concrete Institute guidelines (ACI 318-14, 2014), JSC recommendations which are typical examples of these standards.

In addition, the criteria based on reliability to evaluate the existing structures are represented in various publications, such as: (Schueremans & Van Gemert, 2004), (Ellingwood, 2005).

2.1.1 Performance-Based Design

Design based on performance is a relatively recent framework that adopts an understanding of the structure performance and the purpose of its natural response, in addition to design codes, by studying performance and response objectives. Where it works to meet the level of performance classification that the structure has gained a certain level of risk.

Structural Engineers Association of California SEAOC Vision 2000 (SEAOC, 1995) andNational Earthquake Hazards Reduction Program (NEHRP, 1997) provide further definitions for structure performance levels as shown in the table 2.1.

Table 2.1: Structure Performance Levels According to (NEHRP (ATC.1996), Vision 2000)

Performance level according to NEHRP (ATC.1997)	Performance level according to Vision 2000	Brief description
Operational	Fully Function	There is no noticeable damage in structural and non-structural elements.
Immediate Occupancy	Operational	There is no noticeable damage in structural elements, and other structural components are protected and most of them can do their job if the facility is available.
Life Safety	Life Safety	The presence of damage can be seen in the structural elements, other construction elements are protected, but it does not work.
Collapse Prevention	Near Collapse	Significant damage in the structural elements and

		Non-structural, limited safety margin against the collapse.

2.1.2 The international Code ISO 13822.

The International Organization for Standardization (ISO 13822, 2010) defines the following structural performance levels of the existing structures condition for future requirements of structural performance:

- The level of safety performance: which provides appropriate safety for users of the structure.
- The level of performance that ensures the continuity of the performance of the elements: which secures the continuity of the facilities work such as hospitals, communication buildings, or bridges during and after earthquake, or other expected hazards.
- Special performance requirements: For factors associated with property protection (economic loss or durability).
- The performance is generally based on the cost of the building's life and the specific functional requirements of this Facilities.

2.1.3 International Existing Building Code IEBC 2009.

This comprehensive building code defines the requirements and laws for the existing buildings through directives related to the performance and behavior of the structure (IEBC, 2009).

According to these codes, the evaluation of the structure effectiveness and performance is made up of each component (Structural and non-structural), and the level of structural performance of the building must be determined according to four

Separated and special levels. The four structural performance levels according to these codes are:

- Immediate occupancy
- Life Safety
- Collapse prevention
- Not considered

The middle areas for structural performance are:

- Damage control Rang
- Limited Safety Rang

These research studies and codes dealt with the study of existing structures evaluation from the structural point of the economic view (moral and physical loss values), and these codes have set marginal values for damage levels, it can be formed in the structural elements, and the evaluation levels are divided according to these values into five levels.

In the following order:

- The element is intact (Operational).
- The element meets the function (Functional).
- The element meets the functional in a limited fashion (Limited Function).
- The element does not meet the function (dysfunctional).
- The element is in breakdown (Collapse).

And these codes set values that determine the physical loss ratios for the elements based on the type and severity of the damage, to calculate the value of the material loss of the damaged facility.

The large and comprehensive information’s those provided by these codes for an accurate and comprehensive evaluation process, it makes it an adequate database to be used in the structural and economical evaluation.

2.1.4 Damage Evaluation in the Reinforced Concrete Structures (Analysis and Investigation).

There are several ideas and concepts to be aware of (Pepenar, 2009):

- The analysis of the whole structure should be considered to its initial design, and should also be considered as well when assessing its condition until the damage has occurred.
- Should consider other damages as well like the causes of damage resulting from corrosion are numerous and must be properly and fully identified, and they must be determined also considered causes other than erosion, which are harmful to the structure.
- The damage caused by the surrounding harmful environment appears on limited parts of the elements, but the approved solution must include the structure as a whole. Also, some local damage is caused by corrosion and rust can lead to a change in the mechanisms of distributing loads in the basic design of the structure.
- Investigation, analysis, evaluation and design work are interrelated together fundamentally.

2.1.5 Typical Steps for the Evaluation Process of Damaged Reinforced Concrete Structures

The evaluation process of the damaged facilities consists of the following steps (Fédération internationale du béton, 2003):

- Preliminary evaluation on-site (site verification, status of the structure, loading of the element, environmental impacts), more advanced tests are needed.
- Review all relevant documents, including the date of the building, from changes in loading, maintenance and repair operations and any changes that occur therein.
- Make specific tests and measurements on the site (such as load check, making sure the resistance of materials and elements).
- Analyze the collected data to reach the correct visualization of the structure state and its resistance.
- A careful re-analysis of the structure after it has been subjected to the calculations and new measured loads to know the true amount of the elements and materials resistance.
- Analysis and investigation the possibility of approval of origin and classification of its level of safety.
- Taking appropriate decisions.

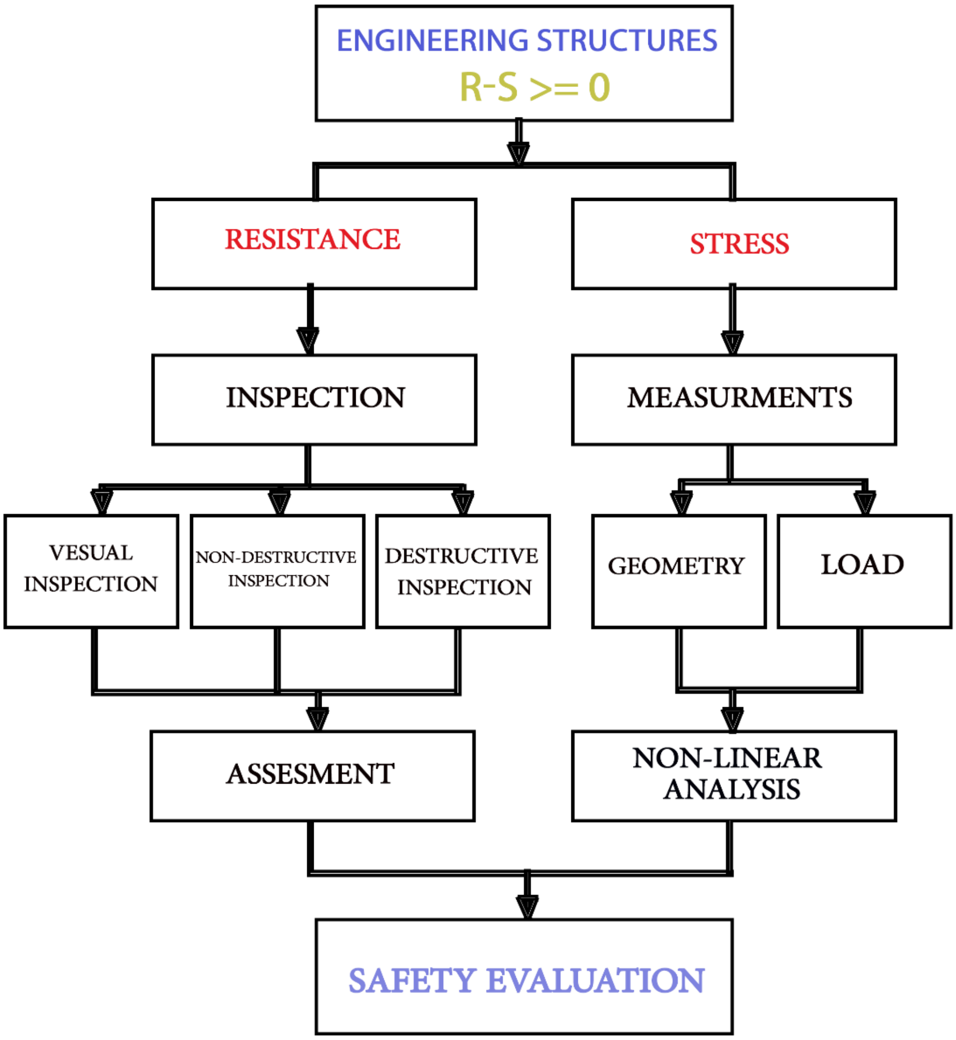


Figure 2.1: Flowchart of Typical Safety Steps Evaluation of the Structure (Fédération internationale du béton, 2003)

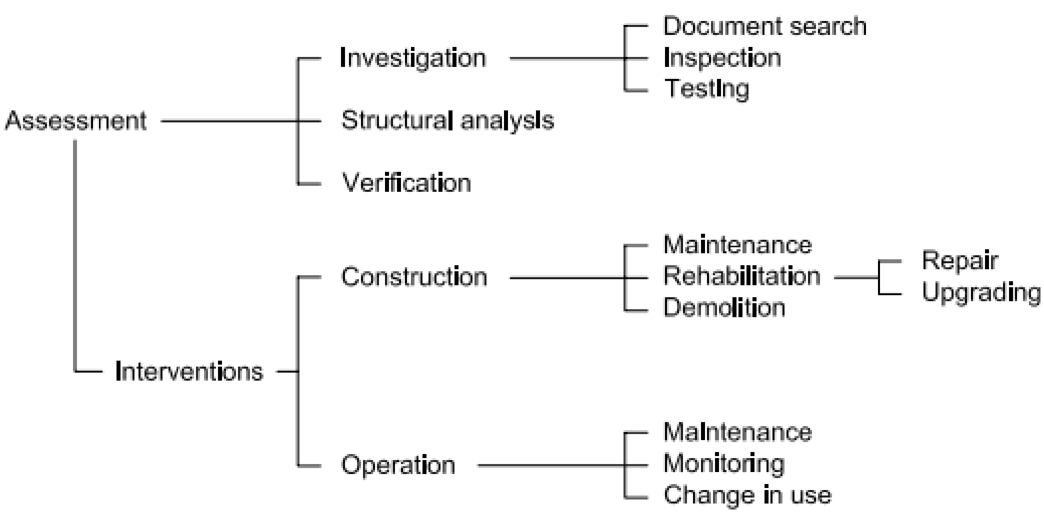


Figure 2.2: Chart of Hierarchy of Terms

The hierarchy terms that mentioned in figure 2.2 are defined below (ISO 13822, 2010).

Assessment: A collection of tasks to check the stability of the current system for the future.

Investigation: Compilation and evaluation of information by means of review, document search, load testing and other tests.

Inspection: Non-destructive on-site inspection to assess the present state of the structure.

Testing: Content performance checks or load tests.

Analysis: The assessment of the consequences of the behavior on the system, the assessment of the causes of the damage or irregular behaviors.

Verification: Setting the target standard of reliability – the level of assurance of reasonable safety and reliability.

Measure: Planned improvements to ensure the required degree of protection and reliability of the system.

Maintenance: Regular operation to preserve adequate systemic efficiency.

Rehabilitation: Work needed to restore, and likely update, the existing structure.

Repair (of the structure): Improve the condition of the structure by repairing or removing existing components that have been damaged.

Upgrading: Improvements to the current structure to boost its structural performance.

Demolition: Work done to remove existing structures.

Monitoring: Frequent or constant, typically long-term, observation or assessment of structural conditions or behavior.

Alteration of the method of use: Specifications for the alteration of the method of use of the current structure to ensure the desired level of safety and reliability of the system.

Till now, the standard evaluation of the existing structure has been reviewed. Afterwards, the blast damaged structure will be reviewed.

2.2 Evaluation of Blast Damaged Buildings

2.2.1 Blast Loading

The explosion creates blast wave the air-blast shock wave is the primary damage mechanism in an explosion. The pressure exerts on building surfaces may be several orders of magnitude greater than the loads for which the building is designed, the shock wave will penetrate and surround a structure and acts in directions such as upward force on the floor system and first impinges on the weakest point in the vicinity of the device closest to the explosion, as the shock wave continues to expand, it enters the structure, pushing both upward and downward on the floor slabs (Nor et al., 2010).

Blast wave is a type of extreme forces that may cause structural failure, it has some common share similarities with seismic loading, some of these similarities include the following (Nor et al., 2010):

- Dynamic loads and dynamic structural response
- Inelastic structural response
- life safety issues & progressive collapse

As well as there are similarities also there are some differences between blast wave and seismic loading, some of these differences include:

- Blast loading is due to a propagating pressure wave as opposed to ground shaking.
- Blast results in direct pressure loading in all directions to structure, whereas a seismic is dominated by lateral load effects.
- Blast loading is of higher amplitude and very short duration compared with a seismic.
- Magnitude of blast loading is difficult to predict and not based on geographical location.
- Blast effects are confined to structures in the immediate vicinity of event because pressure decays rapidly with distance.

2.2.2 Effects of an External blast loading on Concrete Structure

(Ahmad et al., 2012) In this paper, 4 distinct RC wall with varying thickness are taken. These walls are tested with different explosive loads and scaled distance. Pressure sensors, accelerometers, dynamic strain amplifiers, data acquisition board and strain gauges were used to measure air blast and ground shock parameters. In conclusion, it was stated that air blast and ground shock pressure must be considered for accurate analysis of structural response.

(Wakchaure, 2013) Maximum Stress distribution of long and short Side column due to blast loading in this paper, a study was conducted on the behavior of structural concrete subjected to blast loads. The comparison between long side & short side column is made and the further result was presented. In final result percentage of stress of reinforced concrete column for long and short side column were presented in this paper. An extensive parametric study was carried out on a series of 8 columns at the long and short side to investigate the effect of transvers reinforcement, longitudinal reinforcement due to blast loading and finite element package analysis is used to analysis of RC column subjected to blast loading.

(Luccioni et al., 2004) carried an analytical study using AUTODYN software on the failure of RC building subjected to blast load. Then they compared the numerical results with the photograph of real damage caused by explosion has been included. Assuming that 400 kg of TNT placed in the entrance hall of the building. A Lagrange processor is used to solve the columns, beams and slabs which are modeled with 3D solid elements. The results show that the numerical analysis accurately reproduces the collapse of building under blast load confirming the location and magnitude of explosion. They concluded that for this type of analysis simplifying assumptions is to be made for the structure and materials.

2.2.3 Non-Linear Analysis of SDOF System Under Blast Load

The behavior of rigid frames in the inelastic region both under static and dynamic loads has been the subject of many earlier investigators.

Single degree of freedom (SDOF) models have been widely used for predicting dynamic response of concrete structures subjected to blast loading. The popularity of the SDOF method in blast resistant design lies in its simplicity and cost-effective approach that requires limited input data and less computational effort. SDOF model gives a reasonable good result if the response mode shape is representative of the real behavior. The accuracy of dynamic reaction measurements depends heavily on whether the resistance function implemented is identical to the real flexural behavior of the structure.

The methods available for prediction of blast effects on the structures are (Ngo et al., 2007):

- Empirical (or analytical) methods
- Semi-empirical methods
- Numerical methods.

(Hussein, 2010) studied the analytical methods of SDOF system analysis subjected to blast loadings. Two types of blast wave were applied for studying the nonlinear behavior of a system, the analysis focused on the displacement time history responses which develop the basis for studying the behavior of SDOF System under blast loadings. The two types of blast function are a simple pulse and bi-linear pulse. Many parameters have been used for obtaining time history plots, computed energy, and Hysteresis Analysis. The results obtained from a computer program NON-SDOF clarified the effect of type of blast wave on the behavior of the system.

(Singla et al., 2015) reviewed different loading which can occur during a blast. the dynamic impact loading, varying rate concentrated loading & transverse blast loading and the methods applied to analyze those loading phenomena. Single Degree of Freedom (SDOF) model, Finite Element Model (FEM) & non-linear dynamic analysis. The analysis shows that while designing the structure in absence of relevant code is the significant concern behind the ignorance of this phenomenon.

2.2.4 Structural Response to Blast Loading

(Ngo et al., 2007) Complexity in analyzing the dynamic response of blast-loaded structures involves the effect of high strain rates, the non-linear inelastic material behavior, the uncertainties of blast load calculations and the time-dependent deformations. Therefore, to simplify the analysis, a number of assumptions related to the response of structures and the loads has been proposed and widely accepted. To establish the principles of this analysis, the structure is idealized as a single degree of freedom (SDOF) system and the link between the positive duration of the blast load and the natural period of vibration of the structure is established. This leads to blast load idealization and simplifies the classification of the blast loading regimes.

In this paper different methods were introduced to estimate blast loads and structural response such as Elastic SDOF Systems: The actual structure can be replaced by an equivalent system of one concentrated mass and one weightless spring representing the resistance of the structure against deformation. And Elasto-Plastic SDOF Systems: Structural elements are expected to undergo large inelastic deformation under blast load or high velocity impact.

Chapter 3

STANDARDS FOR TECHNICAL EVALUATION

The process of technical and structural evaluation of the structure is a process of detection and verification of structural elements properties and characteristics and to identify all changes and damages to form a complete and sufficient database to determine the level of safety, performance and due processes to improve its performance and continue its work within the requirements of codes related to this field.

The process of technical and structural evaluation in the event of damage is a matter of multi-criteria decision making and must be carried out urgently and decision-making centered on the significance of the various assessment parameters.

Throughout this study, the technical and construction assessment requirements will be analyzed and specified based on a structural history analysis, visual inspection and basic measurements that do not require special tests or checks.

The structural assessment process can be defined on the basis of the following criteria (Kim et al., 2006):

- structural history
- surrounding environment
- structural capability

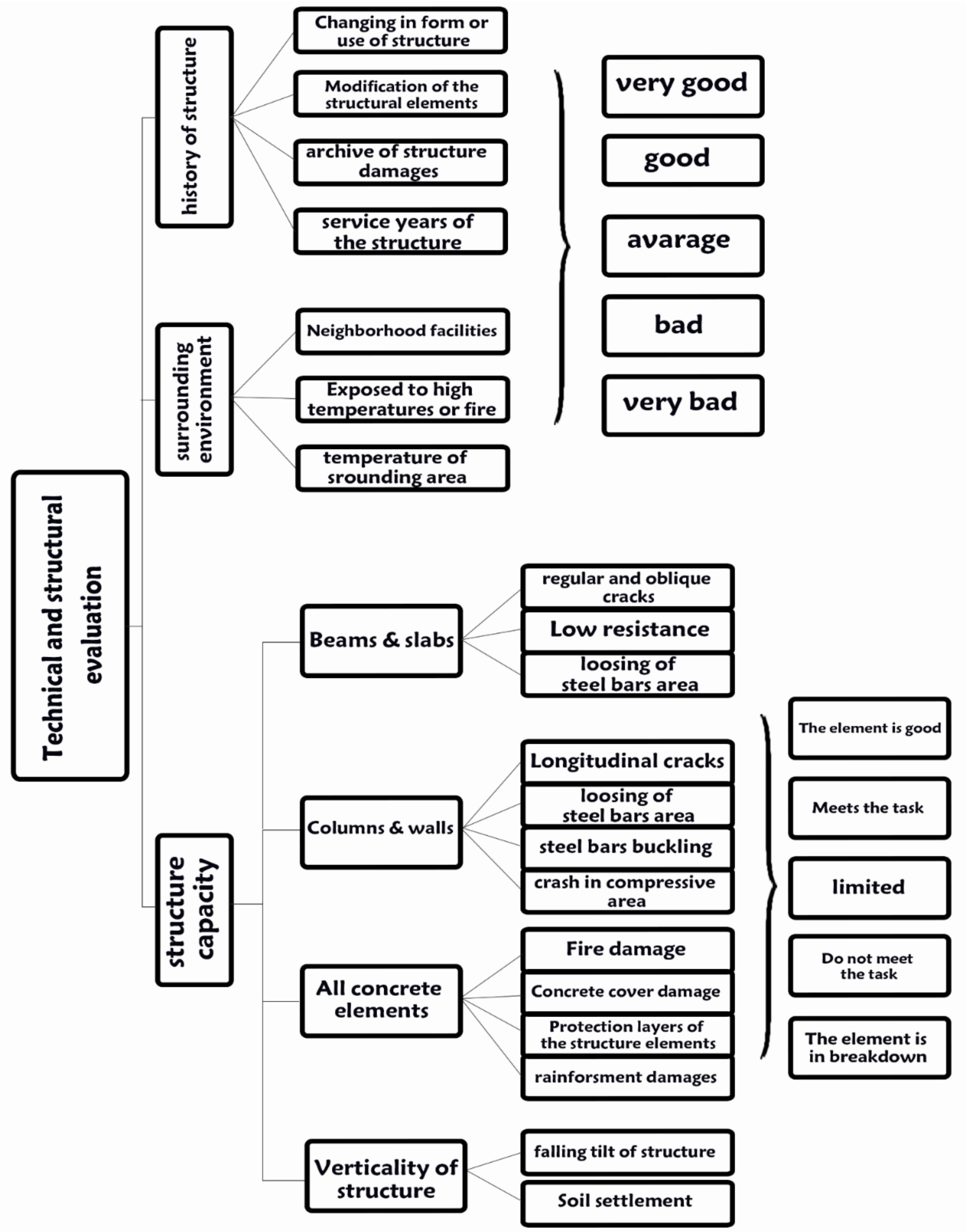


Figure 3.1: Criteria of Structural and Technical Evaluation (Kim et al., 2006)

3.1 Structure History

The history of the structure can be viewed by analyzing the records, archiving and documentation of the structure and it is used to define the transition in the form and use of the building and its components over the planned life of the structure in which the structure is subjected to different forms of events (earthquakes, explosions, explosive loads, floods) and the parameters relating to the past of building have been identified (Hamdia, 2010) as shown in Table 3.1.

Table 3.1: The Evaluation Criteria of the Structure History

	Standard Evaluation	Rating	Characteristics of distortion and damage
Structure History	Changes in the shape and use of the structure	Very good	There is no changing in the shape and use of the structure.
		Good	Partial change in the shape and use of the structure, with a slight increase in the loads.
		Avg	A complete change in the shape and use of the structure, with a slight increase in loads
		Bad	Partial change in the shape and use of the structure, with a big increase in the loads.
		Very bad	A complete change in the shape and use of the structure, with a big increase in loads.
	Modifications of the structure elements	Very good	There is no modification to the structure elements.
		Good	Partial modification of structure elements with slight effect.
		Avg	Moderate strength effect due to a change in the structural elements

		Bad	Severe effect as a result of modifying the structural elements
		Very bad	A complete modification of the structural elements, with severe and wide effect
	Archive of structure damage	Very good	The structure has not suffered by any accidents before
		Good	The structure suffered an accident with minor structural effect
		Avg	The structure suffered an accident with a moderate structural effect
		Bad	The structure suffered more than one accident with severe structural effect
		Very bad	The structure suffered more than one accident with severe and wide structural effect
	Service years of the structure	Very good	The age of the structure is less than 10 years
		Good	The age of the structure is between 10 to 30 years
		Avg	The age of the structure is between 30 to 50 years
		Bad	The age of the structure is between 50 to 70 years

		Very bad	The age of the structure is more than 70 years

3.2 Surrounding Environment

The climate and how good it is will have an impact on the concrete framework and the degree of evaluation of the framework and the physical conditions can occur around the entire structure or some of its elements such as (high temperatures, Moisture and chemicals) which may occur naturally because of the surrounding environment or because of the industrial conditions in which the structure may be invested or revealed and Table 3.2 shows a criterion for assessing the environment surrounding the structure (Hamdia, 2010).

Table 3.2: The Evaluation Criteria of the Surrounding Environment.

	Standard Evaluation	Rating	Characteristics of distortion and damage
Surrounding environment	Degree of surrounding area	Very good	The building is not exposed to salinity damage.
		Good	The density of salt in the atmosphere around the structure is low, far from the sea.
		Avg	The density of salts in the atmosphere around the structure is medium, relatively close to the sea.

		Bad	The structure is exposed to a large density of salts in the surrounding atmosphere, close to the sea.
		Very bad	The building is highly exposed to salts.
	Exposure to temperatures	Very good	The structure is exposed to the normal temperature.
		Good	The structure is exposed to degrees above normal but less than 300° C (concrete color is normal)
		Avg	The structure is exposed to temperature between 300° C to 600° C (concrete color is dark pink).
		Bad	The structure is exposed to temperature between 600° C to 1000° C (concrete color is between dark pink and red).
		Very bad	The structure is exposed to temperature above 1000° C (concrete color is about dark yellow).
	Neighborhood structures	Very good	There are no structures adjacent to it.
		Good	The neighborhood structures were damaged, but not affected.
		Avg	The neighborhood structures were damaged, slightly affected.

		Bad	The neighborhood structures were damaged, severe affected.
		Very bad	Sever structural affect duo to neighborhood structures.

3.3 Structural Capacity

The evaluation process of the structural capacity of the structure elements depends on calculating the percentage of damage as the shape of the damage, its type and its dimensions, and the measurement process should be accurate, for this we can use non-destructive measuring devices for the elements to measure such damages, as the tool can be used Cyclometer to measure the real resistance of the element and compare it with the designed resistance to calculate resistance loss in this element, devices based on principle can also be used X-rays or electrical impulses to measure the corrosion rate of the steel bars (FEMA, 2018).

For the condition of the structural elements according to (FEMA, 2018), five classifications will be adopted, respectively:

1- The element condition is good.
2- The element condition meets the requirement (acceptable).
3- The element condition meets the requirement in limited way (unacceptable).
4- The element condition does not meet the requirement (unacceptable).
5- The element is in breakdown.

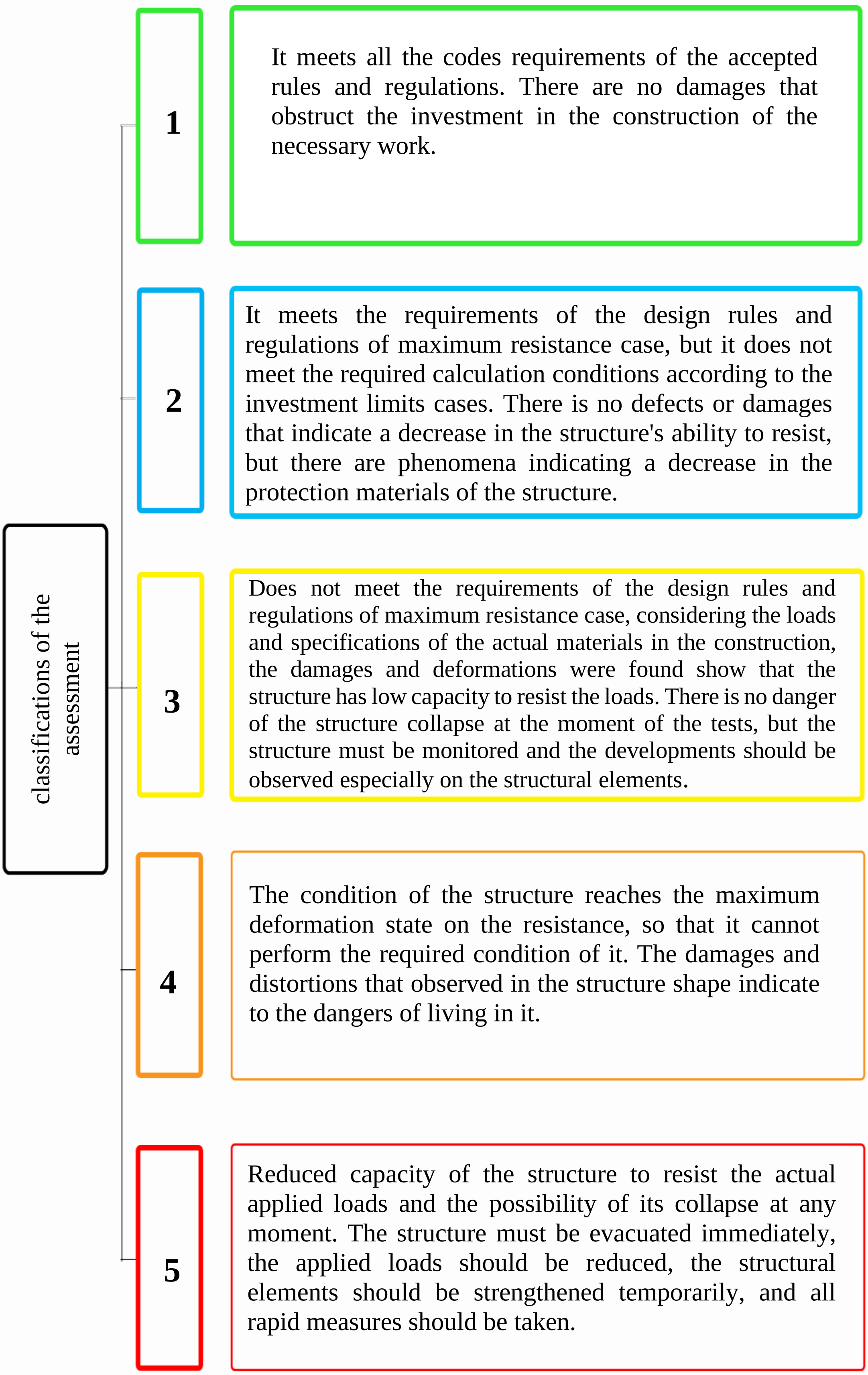


Figure 3.2: The Classifications of the Assessment (FEMA, 2018).

3.3.1 Beams and Slabs

Table 3.3 represents the marginal values of the damage types (Regular and Oblique Cracks, Buckling and Reduction of Steel Area) in the structural elements (Beams and Slabs).

Table 3.3: The Evaluation Criteria of the Beams and Slabs (FEMA, 2018)

Type of damage	Classification of the element	Marginal values of deformation or damage
Regular cracks	The element condition is good	0.1mm
	The element condition meets the requirement	0.3 mm
	The element condition meets the requirement in limited way	0.5 mm
	The element condition does not meet the requirement	1 mm
	The element is in breakdown	More than > 1 mm
Oblique cracks	The element condition is good	--
	The element condition meets the requirement	0.2 mm
	The element condition meets the requirement in limited way	0.3 mm
	The element condition does not meet the requirement	0.4 mm
	The element is in breakdown	More than > 0.4 mm
	The element condition is good	--

Beam buckling	The element condition meets the requirement	1/150
	The element condition meets the requirement in limited way	1/100
	The element condition does not meet the requirement	1/75
	The element is in breakdown	1/50
Low resistance %	The element condition is good	--
	The element condition meets the requirement	--
	The element condition meets the requirement in limited way	20
	The element condition does not meet the requirement	30
	The element is in breakdown	More than >30
Reduction in the steel area due to oxidation%	The element condition is good	--
	The element condition meets the requirement	5
	The element condition meets the requirement in limited way	10
	The element condition does not meet the requirement	20
	The element is in breakdown	More than >20

3.3.2 Columns and Walls

Table 3.4 represents the marginal values of the damage types (Longitudinal and Oblique Cracks, Reduction of Steel Area and Buckling of Steel Bars) in the columns.

Table 3.4: The Evaluation Criteria of the Columns and Walls (FEMA, 2018)

Type of damage	Classification of the element	Marginal values of deformation or damage
longitudinal cracks	The element condition is good	--
	The element condition meets the requirement	0.2 mm
	The element condition meets the requirement in limited way	0.3 mm
	The element condition does not meet the requirement	0.4 mm
	The element is in breakdown	More than > 4 mm
Oblique cracks	The element condition is good	0.1 mm
	The element condition meets the requirement	0.3 mm
	The element condition meets the requirement in limited way	0.4 mm
	The element condition does not meet the requirement	0.5 mm
	The element is in breakdown	More than > 0.5 mm
	The element condition is good	5

Crush in concrete cover %	The element condition meets the requirement	10
	The element condition meets the requirement in limited way	15
	The element condition does not meet the requirement	25
	The element is in breakdown	More than >25
Reduction in the steel area due to oxidation%	The element condition is good	--
	The element condition meets the requirement	5
	The element condition meets the requirement in limited way	10
	The element condition does not meet the requirement	20
	The element is in breakdown	More than >20
Buckling in the steel bars	The element condition is good	-
	The element condition meets the requirement	-
	The element condition meets the requirement in limited way	-
	The element condition does not meet the requirement	+
	The element is in breakdown	+

3.3.3 Concrete Covers and all Concrete Elements

Table 3.5 represents the marginal values and significant signs of the damage in the concrete covers and steel bars.

Table 3.5: The Evaluation Criteria of All Concrete Elements (FEMA, 2018)

Type of damage	Classification of the element	Marginal values of deformation or damage
Protection layers of structural elements	The element condition is good	No damage in the concrete, few capillary cracks in the un-insulated surfaces.
	The element condition meets the requirement	There is damage in the protective layers, there are oily, wet, or salty stains.
Concrete covers	The element condition is good	The thickness of concrete cover layer is 20% less than the design.
	The element condition meets the requirement	The thickness of the concrete cover layer is less than the design by up to 30% and within an area of no more than 30% of the element surface.
	The element condition meets the requirement in limited way	Exposure of stirrups or main steel bars or disconnection of some of them, the absence of cracks in this area.

	The element condition does not meet the requirement	Crumbling in the main concrete section after cover layers.
	The element is in breakdown	Crumbling in the main concrete section after the covering layers and breakdown of the aggregate
Steel reinforcement damages	The element condition is good	The steel bars surfaces are clean after inspection.
	The element condition meets the requirement	There are oxidation phenomena in the stirrups or on the protection layers in some areas, but not in the main steel bars.
	The element condition meets the requirement in limited way	There is oxidation phenomena or stains in the main steel bars at longitudinal cracks area.
	The element condition does not meet the requirement	Interruption in the beam steel bars at the oblique cracks area, buckling or bending of the columns steel bars.
	The element is in breakdown	Interruption in the columns steel bars and compacted elements, interruption in the tension areas or buckling in the compacted areas.

Table 3.6 represents the marginal values of the damages in the surface of the structural elements due to bomb and fire affects.

Table 3.6: Structural Evaluation of The Reinforced Concrete Elements as a Result of the Bombs and Fire (Ross et al., 1991)

Type of damage	Classification of the element	Marginal values of deformation or damage
Disassembling of concrete layers due to bombs or fire	The element condition is good	--
	The element condition meets the requirement	There are no more than three areas in the concrete cover layer and no more than 30 cm² in each area.
	The element condition meets the requirement in limited way	There are more than three areas in the concrete cover layer and no more than 50 cm² in each area except connection areas.
	The element condition does not meet the requirement	Depth more than the covering layers, but not more than 5 cm, except in the connection areas.
	The element is in breakdown	The depth more than 5 cm
Cracks in the concrete due	The element condition is good	0.1 mm
	The element condition meets the requirement	0.3 mm

to bombs and fire	The element condition meets the requirement in limited way	0.5 mm
	The element condition does not meet the requirement	1 mm
	The element is in breakdown	> 1 mm
Loss of resistance due to bombs and fire	The element condition is good	--
	The element condition meets the requirement	5
	The element condition meets the requirement in limited way	20
	The element condition does not meet the requirement	30
	The element is in breakdown	> 30
Changes in concrete color	The element condition is good	--
	The element condition meets the requirement	--
	The element condition meets the requirement in limited way	Dark pink
	The element condition does not meet the requirement	From dark pink to red
	The element is in breakdown	To dark yellow

3.3.4 Verticality of the Structure

As it is represented in Table 3.7 the evaluation criteria of structure verticality can be classified upon the marginal values of the floor displacement and soil settlement.

Table 3.7: The Evaluation Criteria of Structure Verticality (FEMA, 2018)

Type of damage	Classification of the element	Marginal values of deformation or damage
Structure tilted	The element condition is good	Floor displacement is less than $0.004h_f$
	The element condition meets the requirement	Floor displacement is between $0.005h_f$ to $0.007h_f$
	The element condition meets the requirement in limited way	Floor displacement is between $0.008h_f$ to $0.01h_f$
	The element condition does not meet the requirement	Floor displacement is between $0.01h_f$ to $0.012h_f$
	The element is in breakdown	Floor displacement is more than $> 0.012h_f$
Soil settlement	The element condition is good	There is no evidence of soil settlement.
	The element condition meets the requirement	Cracks appear in non-structural elements (approximate settlement > 50mm)
	The element condition meets the requirement in limited way	Cracks appear in non-structural elements, and slight cracks in the structural elements due to foundation settlement.
	The element condition does not meet the requirement	A lot of cracks in the structural elements due to foundation settlement.
	The element is in breakdown	Severe cracks in the structure (≥ 1000 mm)

Chapter 4

ASSESSMENT OF BLAST DAMAGE

4.1 Destructive Factors of the Blast

In order to know how different structures, behave due to blast pressure loads, we need to know the destructive factors resulting from the blast as they are shown in Figure 4.1 (Ngo et al., 2007).

The blast has four main effects (Shepherd, 2009):

1- Blast wave.

It is a huge pressure in the air happens in form of a strong pressure wave as it is described in Figure 4.2, followed by a vacuum, especially in the circle close to the site of the explosion, where it leads to throwing up everything around it and makes cracks, deformation and damages in Structural or non-structural elements (The shock wave is the most important factor in the effects of the explosions).

2- High temperature.

The blast within the circuit of blast site generates high thermal energy represented by a burning flame at high temperatures, this flame may be instantaneous and concentrated, but in other cases it may lead to the ignition of fires in structures that negatively affect the properties of the structural materials.

3- Shrapnel.

Due to high pressure, the explosion results in flying shrapnel of explosive material, in addition to pieces and sections of the explosion site that are randomly flowing, which are of great danger to surrounding structures and facilities, as they can interfere with sections of the structural elements and lead to their collapse or harm partially or completely, in addition to break the covering materials.

4- Sound wave.

The fourth effect arising from the explosion is the loud sound, which is not known to be very damaging compared to the previous three effects.

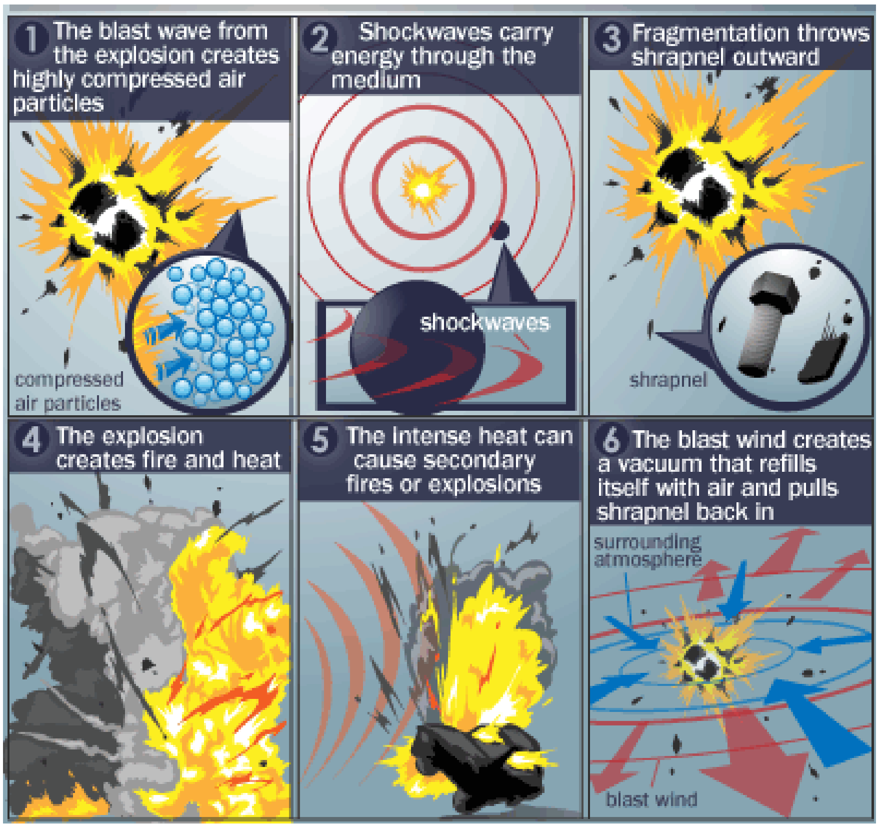


Figure 4.1: Destructive Factors Resulting from the Blast (Ngo et al., 2007)

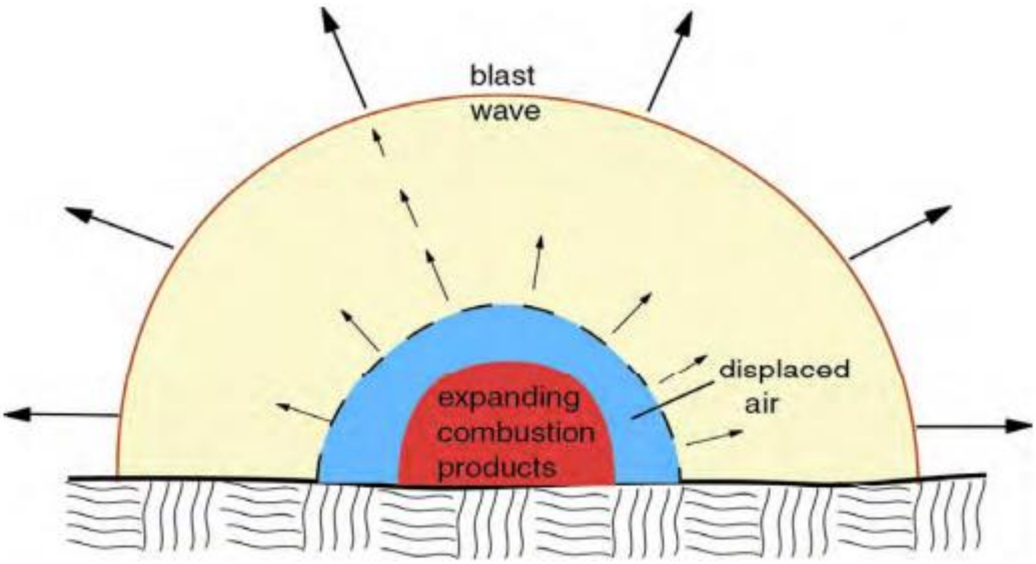


Figure 4.2: Blast Wave (Shepherd, 2009)

4.2 Technical Difficulties in the Assessment Process of Blast Damage

Engineers and technicians face a set of difficulties when they work for evaluating the damage structures due to an explosion. They need a logical and accurate analysis of the problem in order to reach the most appropriate solutions, and some of these difficulties are summarized in the following items (Ross et al., 1991):

- The load: where the load is related to four coordinates, which are P (X, Y, Z, T), which are the spatial coordinates in the place, in addition to the time factor and estimating the value of the load is not an easy thing.
- Non-linear dynamic structural behavior: Represented by changes in engineering specifications (dimensions and sizes) in addition to the properties of the construction materials.
- Reaction of structural components: It is defined by the adjustment of certain structural functions of some bearing elements due to the dynamic behavior of other elements, and by the attempt of the facility to rotate the moments and to rebalance itself.

- The capability of materials to breakage or survival after the explosion, according to their nature and durability.
- The difficulty of accurately describing the damage occurring to all elements of the structure.

Most of these items are not easy to classify or describe.

4.3 Evaluation and Estimations of the Deformation due to Blast Loads Applied to Structural Elements

A preliminary review should be performed rapidly and carefully to assess the applied blast load and the type of damage and then to recommend some immediate steps of temporary protection at its general level. Following this, a systematic and thorough review will be carried out to assess the actual strength and toughness of the damaged structure in order to draw the strengthening and repairing paths (Ngo et al., 2007).

When carrying out the evaluation of blast load deformation of the structure, several points must be taken into consideration, and these points are summarized as follows:

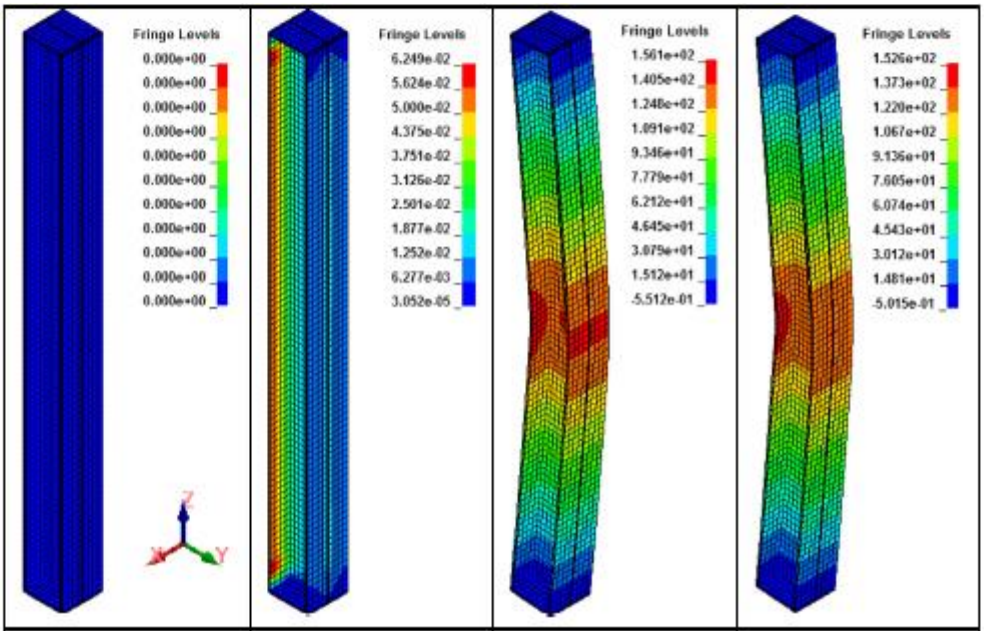
1- The level of structural safety: The level of structural safety of the structure is of primary importance, because it is the duty of the engineer to conduct the evaluation process to assess the structural state of the building and whether it is possible to enter the building and carry out the required evaluation or not.

2- The type and the investment function of the structure: The investment function of the structure comes in second place in terms of importance and the necessity to restore the building to life, depending on the investment needs in the building, as in the case of earthquake resistance design and the important considered factor in the seismic calculation, this factor can be valid in the case of evaluating the damaged facilities.

3- The possibility to rehabilitate and re-invest the building: In the third place comes to the possibility of rehabilitating the building and reinvesting it, this issue is controlled by the economic factor after the first and second factors. As an example, we cite a case in chapter 6 discusses the possibility of rehabilitation of a structure in Benghazi.

4.3.1 Blast Pressure Load on the Structure

The blast load acting on the elements of the structure can be estimated by using a numerical investigation, such as explicit finite element analyses (LS-DYNA) (Momeni et al., 2019). Figure 4.3 shows some visual results of IPB300 steel column under blast load at several time instants the way to the formation of flexural plastic hinge at the column mid mid-span resulted from extreme deformations under simultaneous effects of blast and initial axial loads. The fringe levels represent the displacement in Y direction which is used to evaluate damage based on support rotation criterion to see deformation and compare it with real deformation.



t=0 msec	*t= 49.99 msec*	*t=60.5 msec*	*t=150 msec*
No blast load No axial load	No blast load Axial load is 20% of axial capacity	During blast load Axial load is 20% of axial capacity	Blast load was finished Axial load is 20% of axial capacity Nodal velocities are vanished
Y_{max}= 0	Y_{max}=0	Y_{max}=141.96 mm	Residual Y_{max}=136.4 mm

Figure 4.3: The Computer Modeling for a Column Deformation Due to Blast Pressure Load (Momeni et al., 2019).

4.3.2 Response of Structural Element due to Blast Pressure

The structural elements have different responses to the exposure effects of blast pressure loads according to factors. Which are given below (Ngo et al., 2007) (Magnusson, 2007):

1- Structure design and dimensions (structural element spacing and element dimensions).

2- Construction materials for the different structural elements of the structure (the homogeneity of the materials and the calibration of the construction materials).

3- The blast distance from the structure and the location of the explosion.
4- The source and type of the explosion
5- The general position of the explosion (presence of dampers or surrounding structures that tend to reduce the shock).

The response pattern of the various structures and their components under the influence has different values of the blast pressure (pressure source). The response shape varies from elastic deformation to fragmentation and loss of materials and sometimes crush some parts, up to collapse in some elements and structure parts.

4.3.2.1 Elastic Deformation

All the structural elements with their different types are subjected to elastic deformation as a result of the blast pressure on them (slab, beam, column, concrete wall) (Gantes & Pnevmatikos, 2004), the deformation in the case of explosions is often deformed horizontally and in certain cases it is vertical, the element is subjected to pressure and deforms with it within the positive phase of the shock wave and then returns to its natural state, and in many cases the element reaches the point of cracking while remaining within work ability without loss in the segment as shown in Figures 4.4 and 4.5.

Figure 4.4: The Elastic Deformation in The Beam

Figure 4.5: The Elastic Deformation in the Column

The cause of elastic deformation in structural elements when they are subjected to blast pressure is due to several factors (Stochino, 2016):

- The homogeneity of the element materials and the use of high-quality materials give a good impermeability to the mixture as well as good compactness.
- The use of steel reinforcing grids with small diameters and regular spacings so that they work more closely with concrete to resist the pressure, in addition to the quality of steel reinforcement bonding as shown in Figure 4.6.
- The large distance between the explosion location and the studied structure, so that the pressure does not reach the extent that leads to break it down.

Figure 4.6: Good Steel Reinforcement Bonding

4.3.2.2 Partial Losing in the Material

When the structural element is exposed to a medium-intensity shock or the element is durable so that it does not collapse as a result of the blast, it loses part of its material, while remaining within its service, meaning that the element remains able to work in the marginal state and cannot bear any extra loads as shown in Figure 4.7.

Figure 4.7: Partial Material Losing in A Column

4.3.2.3 Fragmentation and Loss of Materials

Fragmentation usually occurs in structural elements carrying reinforced concrete as a result of strong and direct exposure and is considered to be one of the dangerous situations, because the flying fragments themselves are considered to be shells which cause damage to other structural elements while flying and colliding with them.

The cause of fragmentation in structural elements is often due to two main reasons:

1- Heterogeneity of the concrete section material and weakness of the bond material.
2- The element is subjected to a strong blast load near the edges, which causes the end or the outer part of the element to fragment as shown in Figure 4.8.

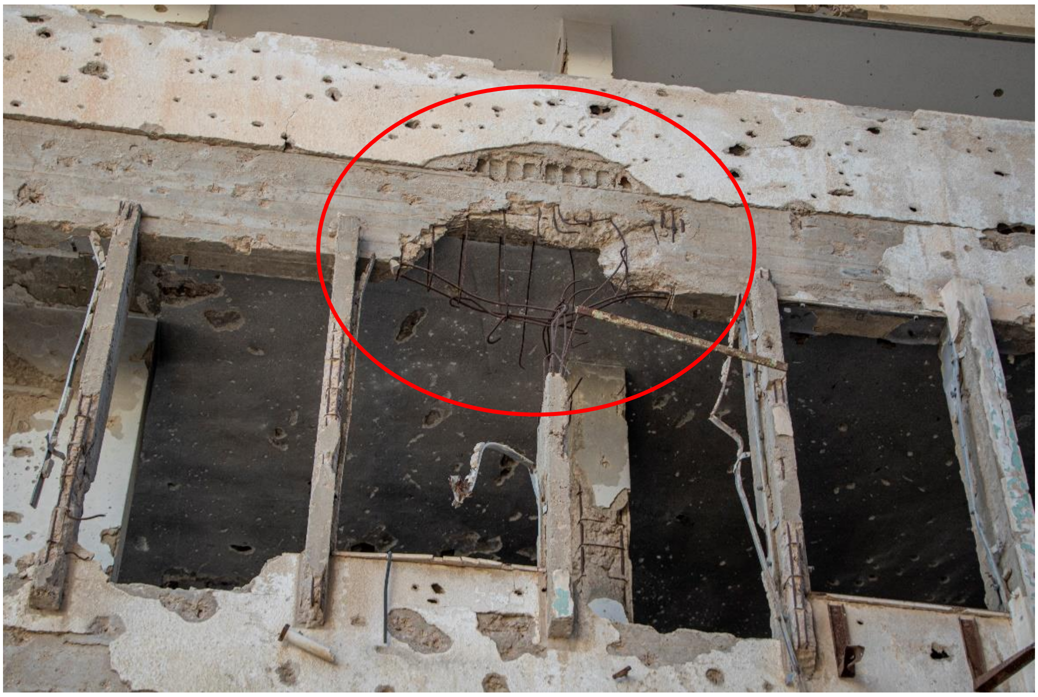


Figure 4.8: Fragmentation and Loss of Materials

4.3.2.4 Partial or Complete Collapse

Partial or complete failure happens to the structure elements that are exposed to an explosion as a result of the structure being within a high blast pressure range or the element being exposed to a high damaging shell that renders it out of service as shown in Figures 4.9, 4.10 and 4.11.

Figure 4.9: Partial Collapse

Figure 4.10: Partial Collapse


Figure 4.11: Total Collapse

Chapter 5

CASE STUDY

The purpose of this case study is evaluating a damaged war building by visual and modeling evaluations for knowing the safety level of the structure and studying the structure behavior and the deformations that occurred and noted in this case in Benghazi. The visual evaluation process is one of the most complicated and dangerous procedures and beside these procedures I have applied modeling evaluation by modeling the damaged structure on one of the computer modeling software for predicting hazard points in the damaged structure and considering one of the main concerns for the protection level of the structure.

5.1 General Information About the Structure

Location: The building located in JAMAL ABDULNASER street close to the central bank of Libya, Benghazi, Libya.

Structural plan: It is a residential building consists five symmetric stories and the whole construction is a concrete structure, the structural system that supports the building is made of solid slabs with 10cm of thickness built on hidden beams with dimensions (20 × 30) cm with steel reinforcement (Top 3Φ16 and Bottom 3Φ18) to columns (30 × 30) cm with steel reinforcement 8Φ14. The total area is approximately 200 m^2 it is 13 m long, 14 m wide and 16 m high. Vertical loads are carried by reinforced concrete slabs that rest on the reinforced-concrete frames. Horizontal loads are carried by mixed frame-wall system with walls towards the neighboring buildings as shown in Figure 5.1. And the material properties were considered and defined in the program as concrete has a cylinder compressive strength of 25MPa (C25), tensile strength of 2.56MPa and elastic modulus of $E=3\times10^{7}$KPa. The reinforcement has a yield strength of 420MPa (S420).

Figure 5.1: Residential Building in JAMAL ABDULNASER Street

5.2 Evaluation and Description of Structure Damage

Blast loading is applied only to the front facade, because it is surrounded by surrounding structures, and the explosive was placed very close to it and the building was exposed to a shell at the middle span of the first floor and this leads to a destroyed in two columns above and connection node on the second floor and the concrete of the columns was shattered, plasticized and the longitudinal and transverse steel bars was cut off.

5.2.1 Visual Evaluation

The middle span in the first floor is completely destroyed and two external columns in the facade on the second floor are completely broken and are out of service as seen in the Figure 5.2, where losses occur in the entire section of the entire axis at the end of the columns and the span between them is also lost with damage in two external beams. There are some damages in the concrete cover of the structure and many cracks in the walls with a big damage in some of them as shown in Figure 5.2.

Figure 5.2: Broken Two Main Columns and Slab

Figure 5.3: Tensile Force in the Columns

5.2.1.1 Results of the Visual Evaluation

The columns come out of the service in the structure, that lead to a drop at the end of the beam that is attached to that column, which lead to a tensile force as it was shown in Figure 5.3, and the column above also exposes to a tensile force due to the lack of support under it, which lead to the occurrence of horizontal cracks resulting from the tension.

5.2.2 Modeling Evaluation

Computer modeling to predict danger points in the blast-destroyed structure is a realistic experience by considering one of the essential issues for determining the degree of structure safety and by predicting the dangerous points that are indirectly affected by the explosion due to the loads redistribution inside the structure when some parts of the facility are destroyed, as well as this method provides a clear understanding of the complete spatial behavior of all the structure elements, which helps to predict the position of the expected stress that occurs in an emergency as a result of re-transfer the loads in the elements at new condition of the structure.

The building was modeled before and after damage in its original structural form by employing modeling software package SAP2000 v 21 as sown in Figure 5.4, and since the building was not damaged in other than these locations which they are mentioned in the visual inspection, it was easy to complete the modeling process, estimate the damage caused, and study the behavior of the structure after the strike by applying the normal gravity loads (1.5KN/m² dead load, 2.0KN/m² live load) on the structure (taking into account that the building is no longer used), The analysis included plastic hinges at the columns' and beams' ends in order to observe the plastic behavior of the structure and analyzed by non-linear static analysis (pushover) for analyzing the deformations and effects resulting from binding moments and shear forces that formed in it based on the current reality.

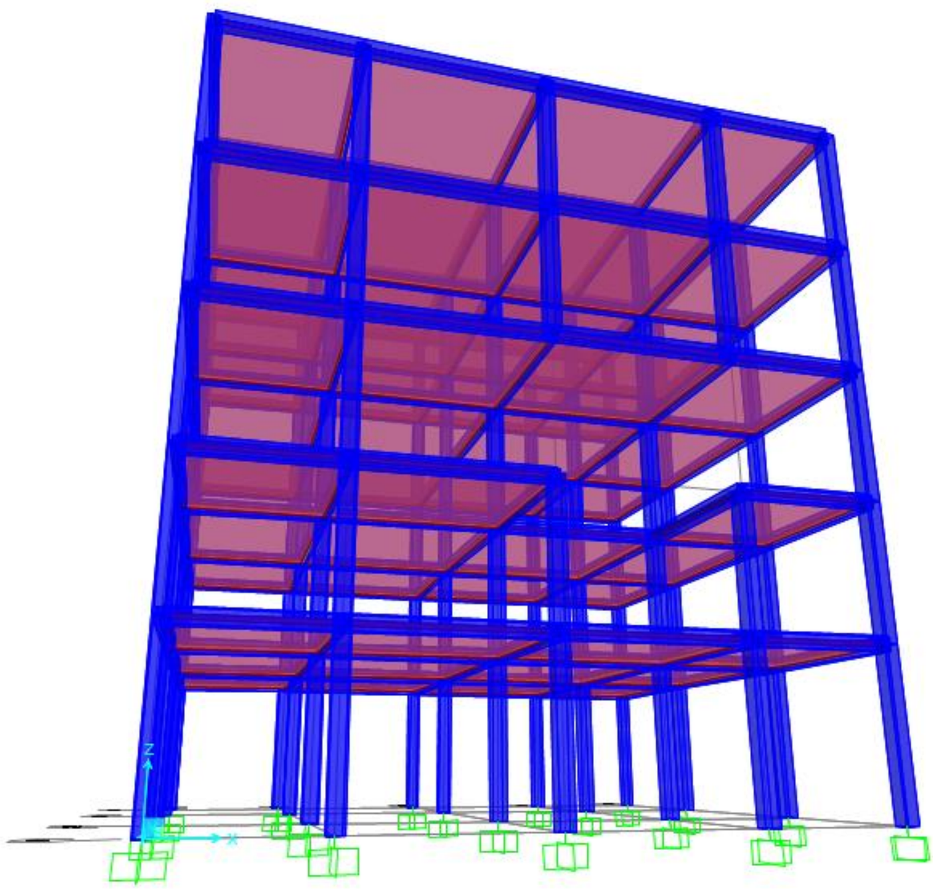


Figure 5.4: Model of Damaged Structure

As shown in Figure 5.5, the columns did not behave completely in the expected behavior to work on tension, but rather it was found in the analysis of these columns, due to the regularity of the construction in terms of the spacing of the structural elements and their uniform distribution, that the floor above the axis of the collapsing columns behaves as a fully individual element.

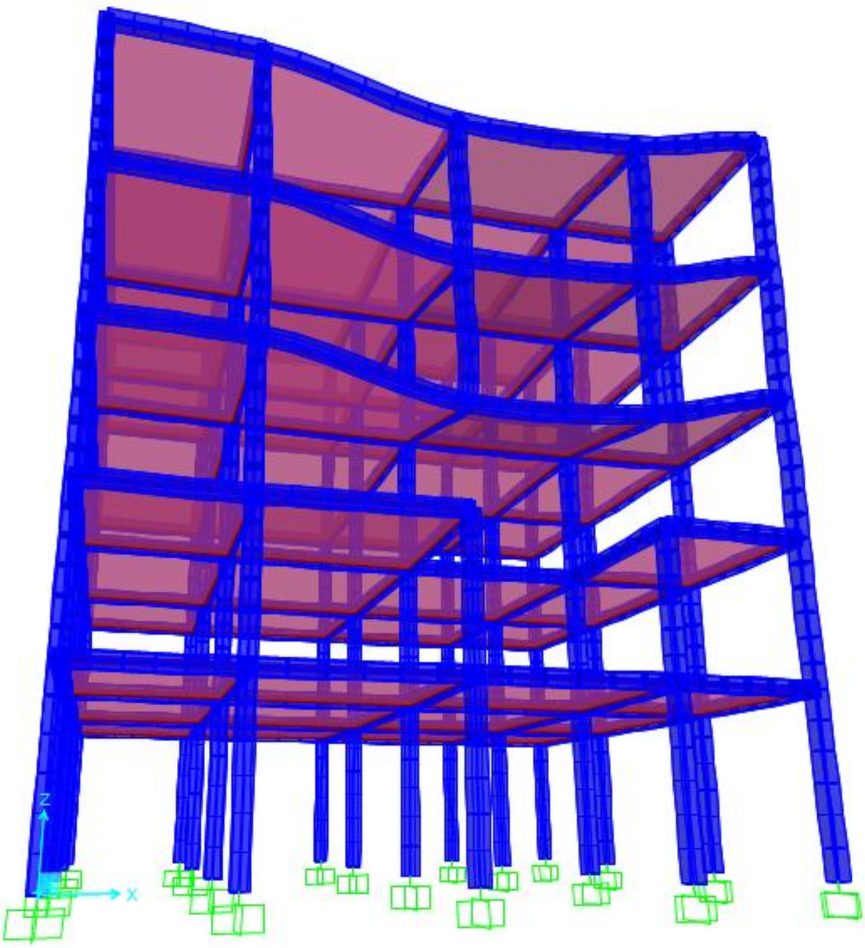


Figure 5.5: Joint Displacement and Structure Deformation

The change in the structural condition of some elements in the structure leads to a noticeable change in the behavior of the elements carrying it, as shown in Figure 5.6 (a) and (b) the change in bending moments of a structural frame before and after the loss of the columns, respectively. (c) shows the possible increase in the bending moment of a structure frame with the failure of the columns. In addition to the presence of a strong negative torque in the upper floors.

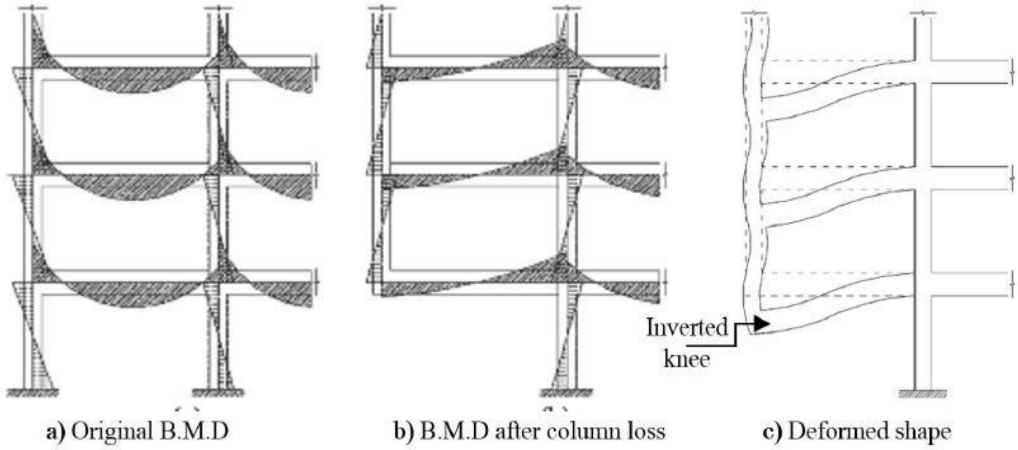


Figure 5.6: Illustration of Moment Redistribution (Yap & Li, 2012)

Figure 5.7 shows the deformed shape of the building from the top, therefore, there is a considerable change in the moment distribution along the beam elements. This change is mainly attributed to the loss of two components of the global vertical load carrying capacity system. Figures 5.8 and 5.9 the circles indicate the bending moments in beams which they are not supported by columns and they were not designed to resist that moment. Accordingly, Table 5.1 records that there is an obviously huge increase in the beams moments after releasing their restrains. The loss of an exterior columns directly affects the vertical load transfer path of the above column. The exterior columns and beams are subjected to a complete change in the direction and distribution of the bending moment, which the elements were not designed for. This change in the moment has caused a variation in the deformation shape of the frame under consideration and thus, higher risk for collapse of the structure.

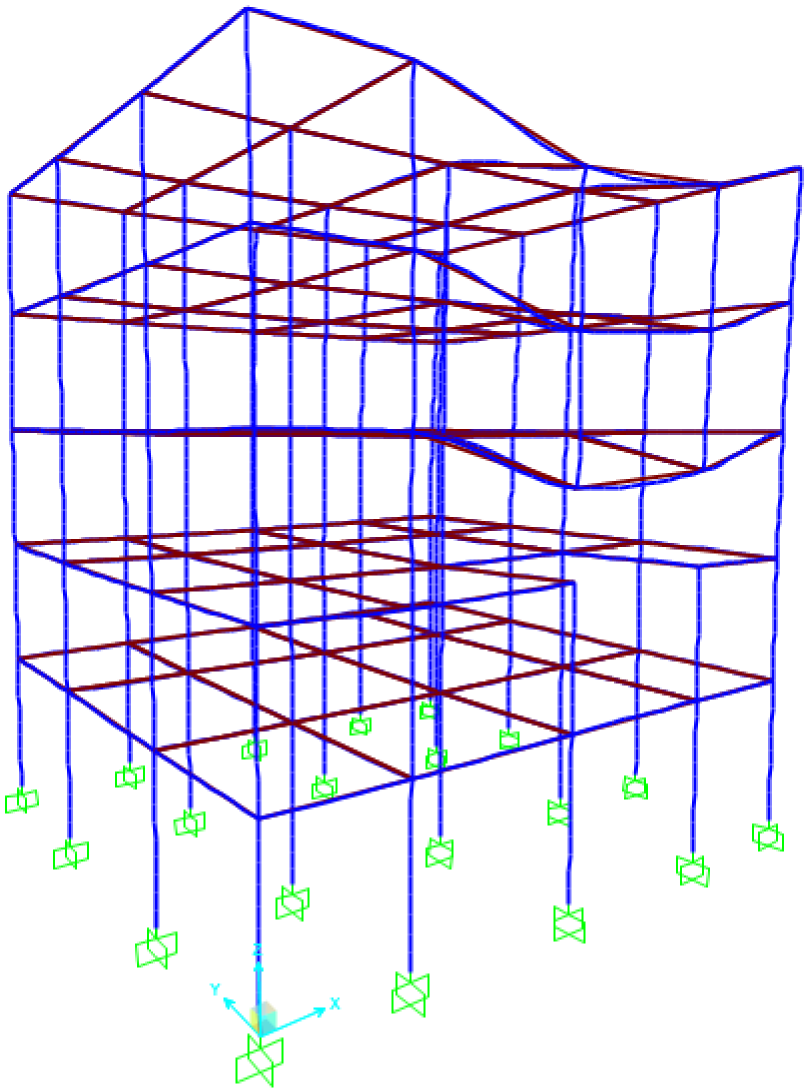


Figure 5.7: Deformed Shape of the Building

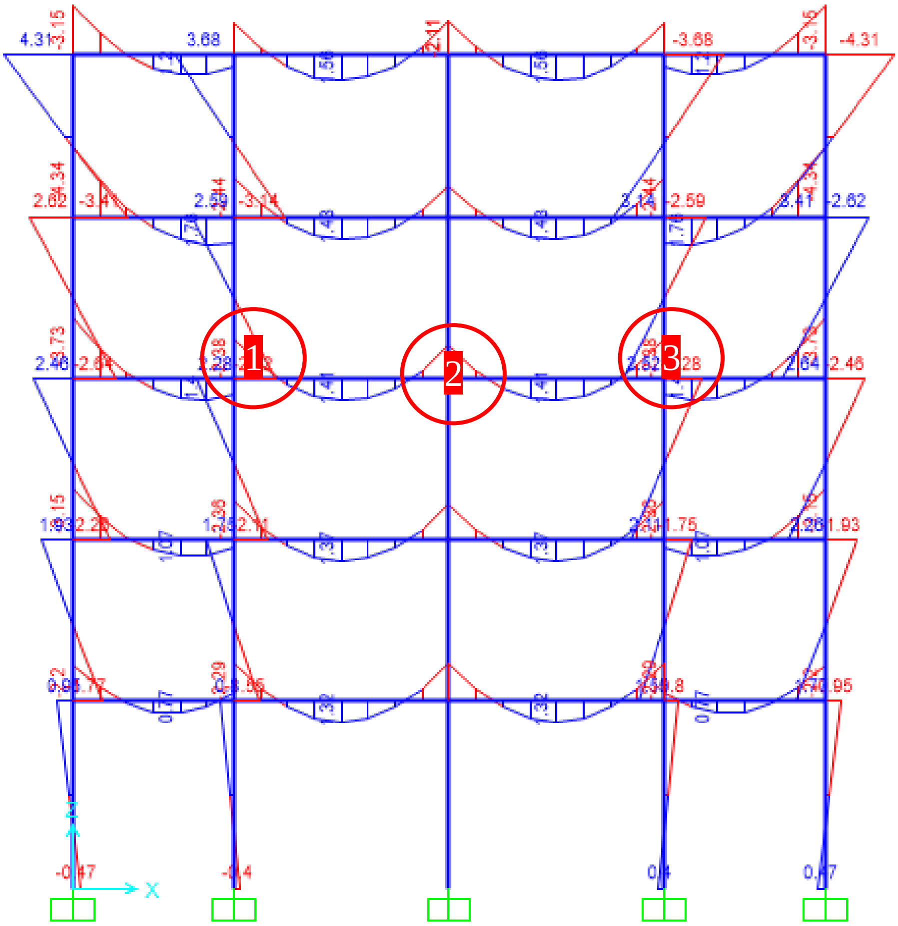


Figure 5.8: Bending Moment Diagram Before Columns Loss

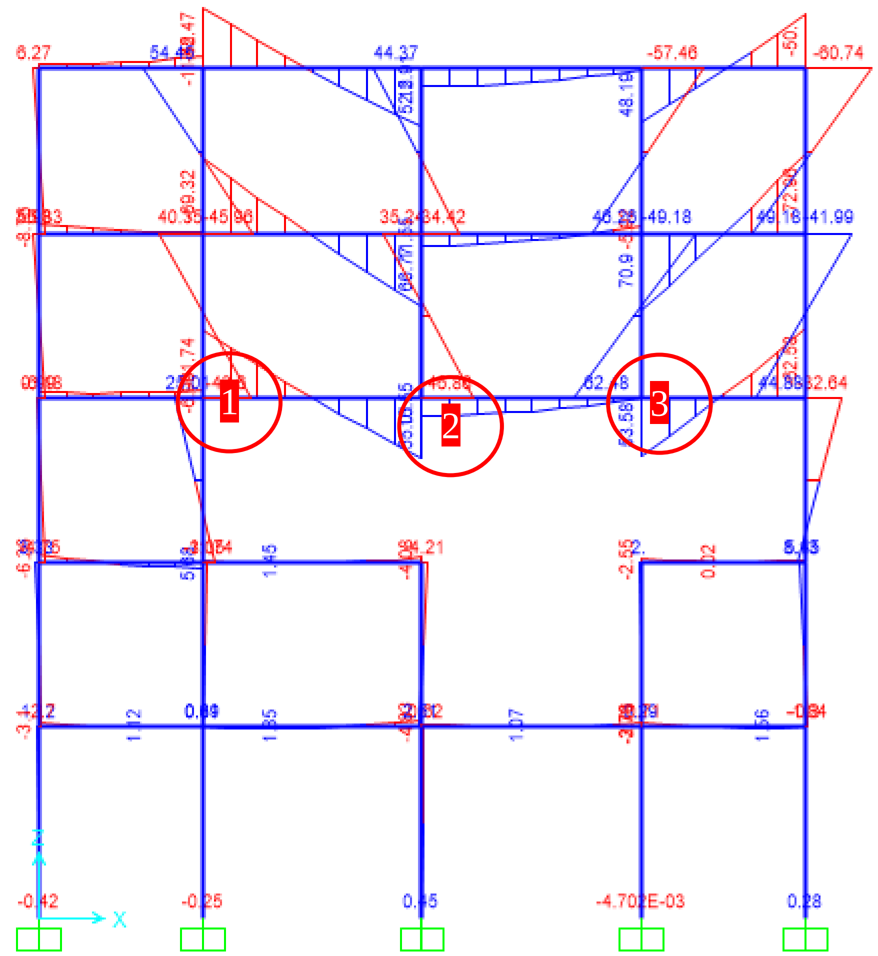


Figure 5.9: Bending Moment Diagram After Columns Loss

Table 5.1: Comparison Between Beams Moments Before and After Columns Loss

Beam #	Moment Location	Before Moment (KN.m)	After Moment (KN.m)
1	Left	-0.6284	-45.5732
	Mid	1.2214	-14.5848
	Right	0.6219	28.5239
2	Left	-0.5876	16.2462
	Mid	1.1108	14.2946
	Right	0.2844	7.993
3	Left	1.4043	35.3414
	Mid	0.7774	-2.4771
	Right	-3.537	-62.579

When we look at the load pathology (load distribution) in Figures 5.10 and 5.11, we found that it is changed and the two side columns in the second-floor expose to about more than 60% of the designed load which means the load on these columns has increased double which causes a bending deformation as a compressive load.

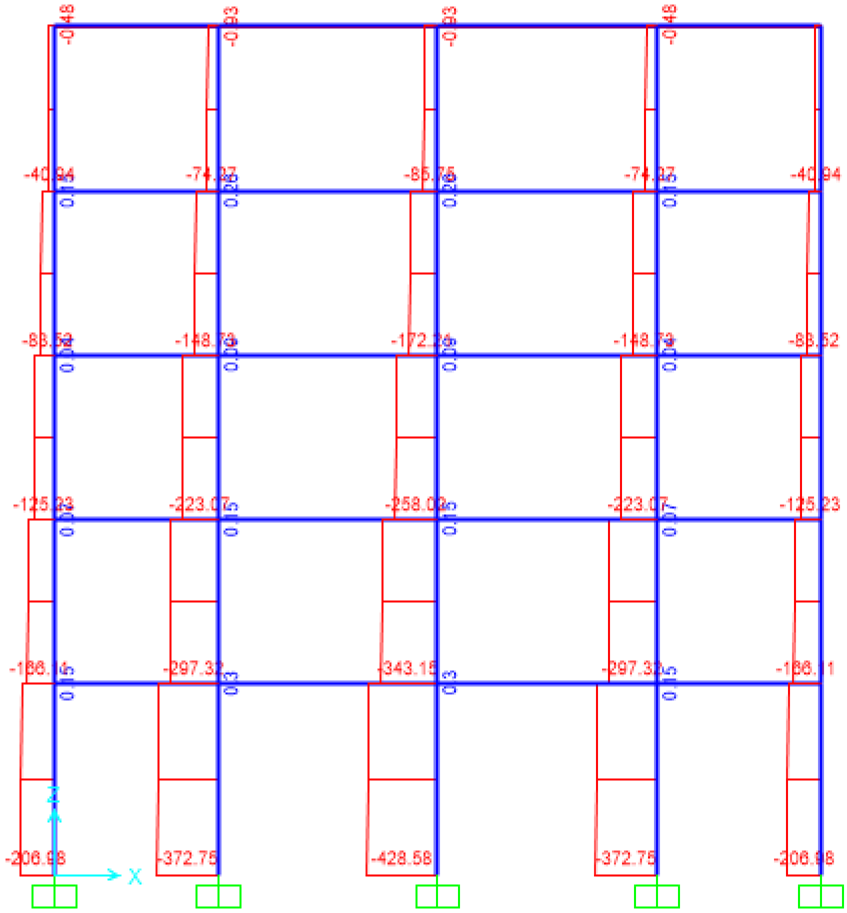


Figure 5.10: Distribution Load Before Columns Loss

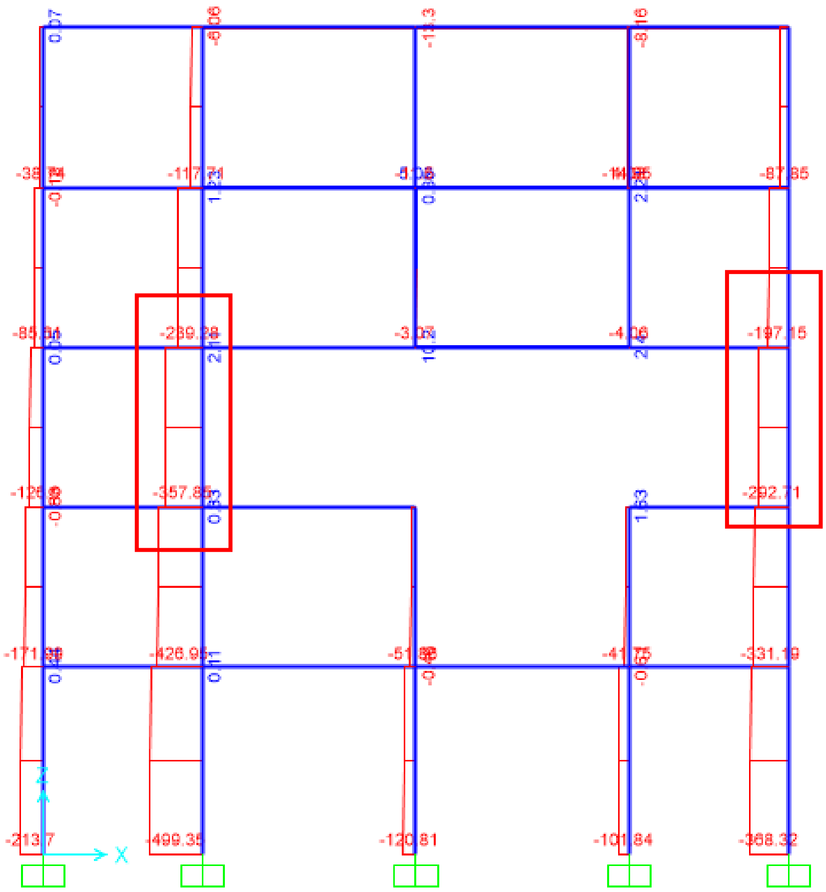


Figure 5.11: Distribution Load After Columns Loss

Figures 5.12, 5.13 displays joints displacement and deformation on the front and Table 5.2 represents the vertical and horizontal displacements of the nodes before and after columns loss, since the structure is a reinforced concrete structure the elements deformation can be specified in terms of support rotations, Figure 5.14 shows the modeling joints at the end of the members as plastic hinges. Figures 5.15 and 5.16 show the plastic hinge development of plastic deformations observed and an extensive plastic deformation can be seen in some elements at the bottom and these elements need for subsequent repair or replacement before they may be re-used. As can be observed in Figure 5.14, three different performance levels were developed which are O (operational) level, IO (immediate occupancy) level, and LS (life safety) level while in Figure 5.16, the developed performance levels are O (operational) level, IO (immediate occupancy) level, and C (collapsed) level. In operational level, very small structural and nonstructural damage can be developed and the occupants are safe during any event. In addition to that, the structure can be reused immediately with losses of less than 5% for replacement purposes. While immediate occupancy holds very limited structural damage and small nonstructural damage. Furthermore, in some cases, the structure cannot function properly but however still safe to occupy with losses of smaller than 15% for replacement purposes. On the other hand, limit safety level shows notable damage in the structural components and extensive for nonstructural ones. Also, injuries can take place with losses not smaller than 30% since the structure requires repairing and maintenance before re-occupancy. Lastly is collapsed level where total and complete damage in terms of structural and nonstructural components occurs with high possibility of injuries and deaths.

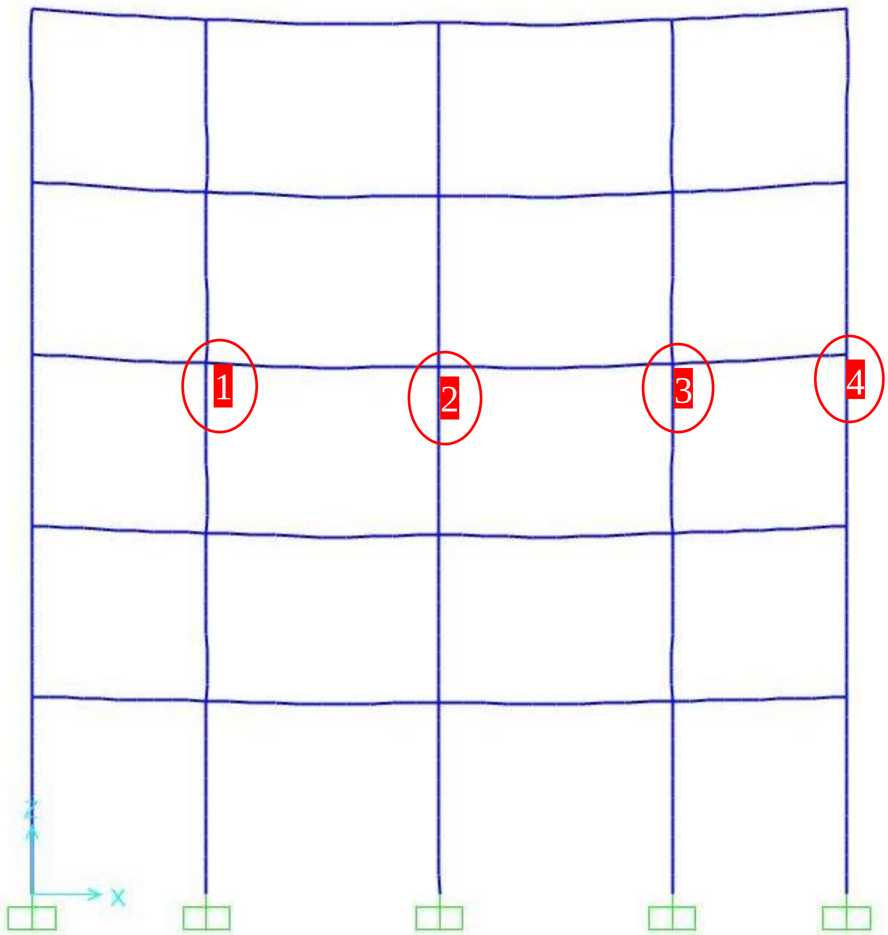


Figure 5.12: Displacement Before Columns Loss

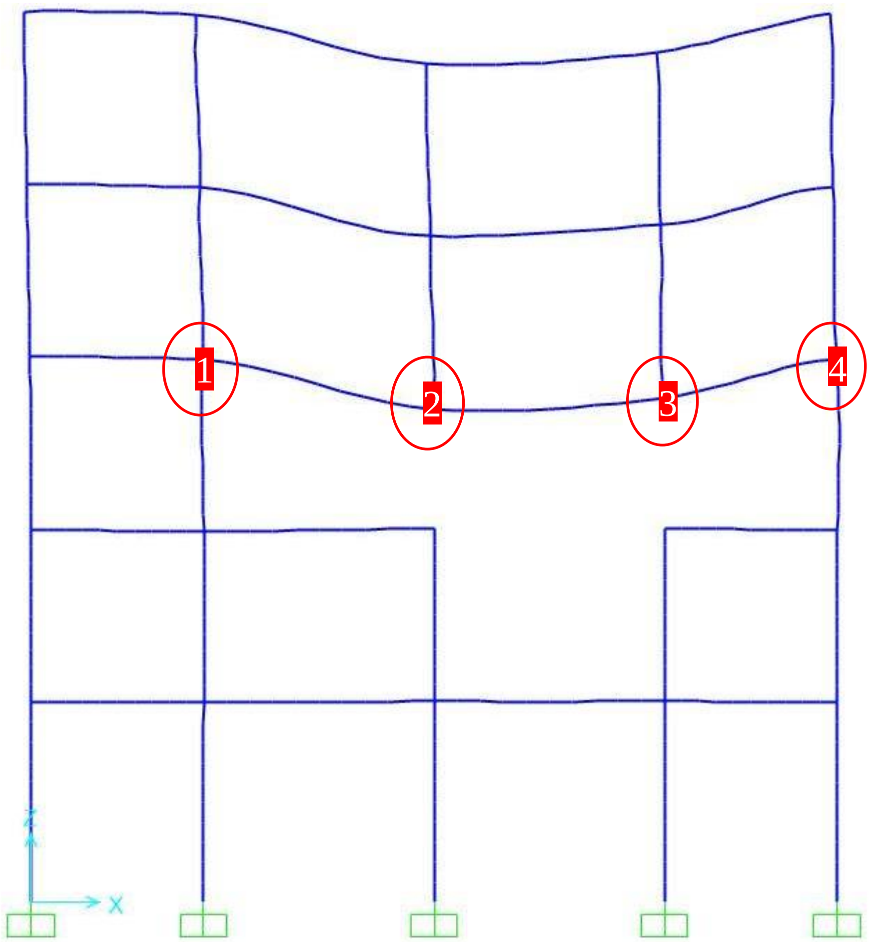


Figure 5.13: Displacement After Columns Loss

Table 5.2: The Vertical and Horizontal Displacements of The Nodes Before and After Columns Loss

Node #	Before			After		
	X(m)	**Y(m)**	**Z(m)**	**X(m)**	**Y(m)**	**Z(m)**
1	1.40E-05	-1.00E-05	**-0.00101**	-0.00025	-0.0006	**-0.00146**
2	1.50E-05	-7.47E-06	**-0.00112**	-0.00024	-0.00071	**-0.01666**
3	1.50E-05	-4.72E-06	**-0.00096**	-0.00022	-0.00083	**-0.01306**
4	1.50E-05	-2.69E-06	**-0.00055**	-0.00022	-0.00092	**-0.00112**

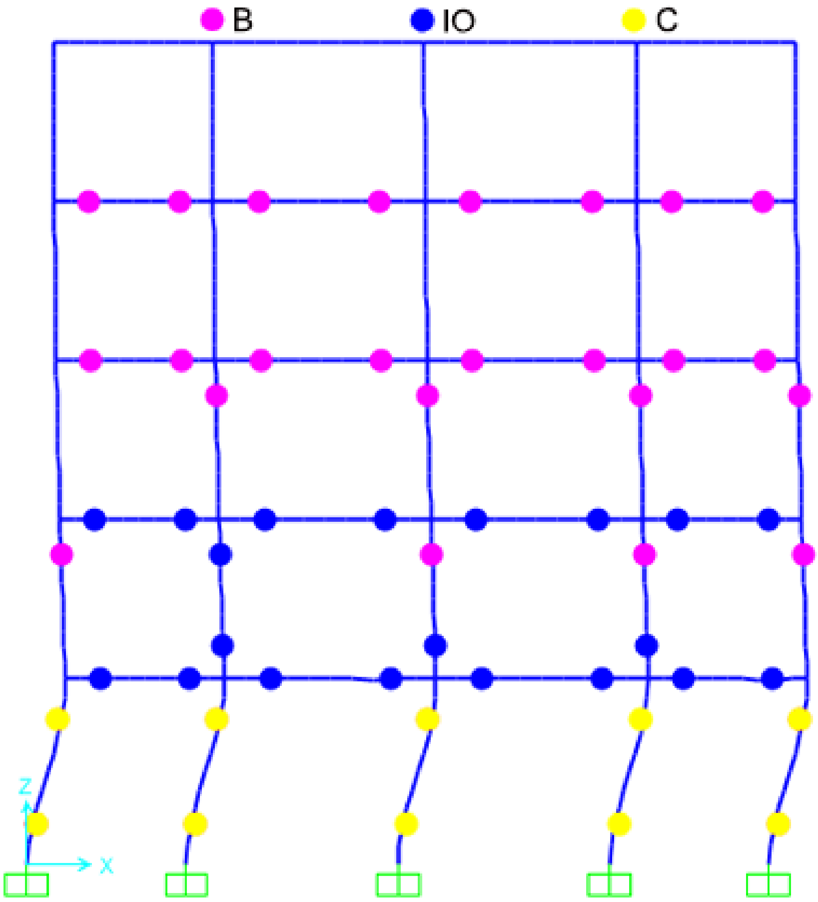


Figure 5.14: Plastic Hinges Before Columns Loss

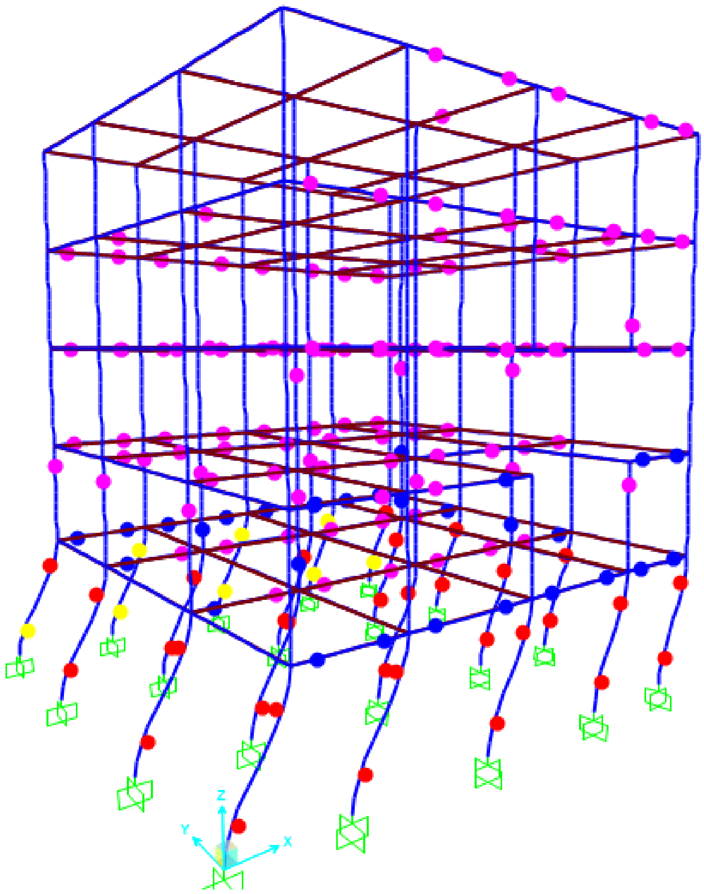


Figure 5.15: Plastic Deformations After Columns Loss (3D)

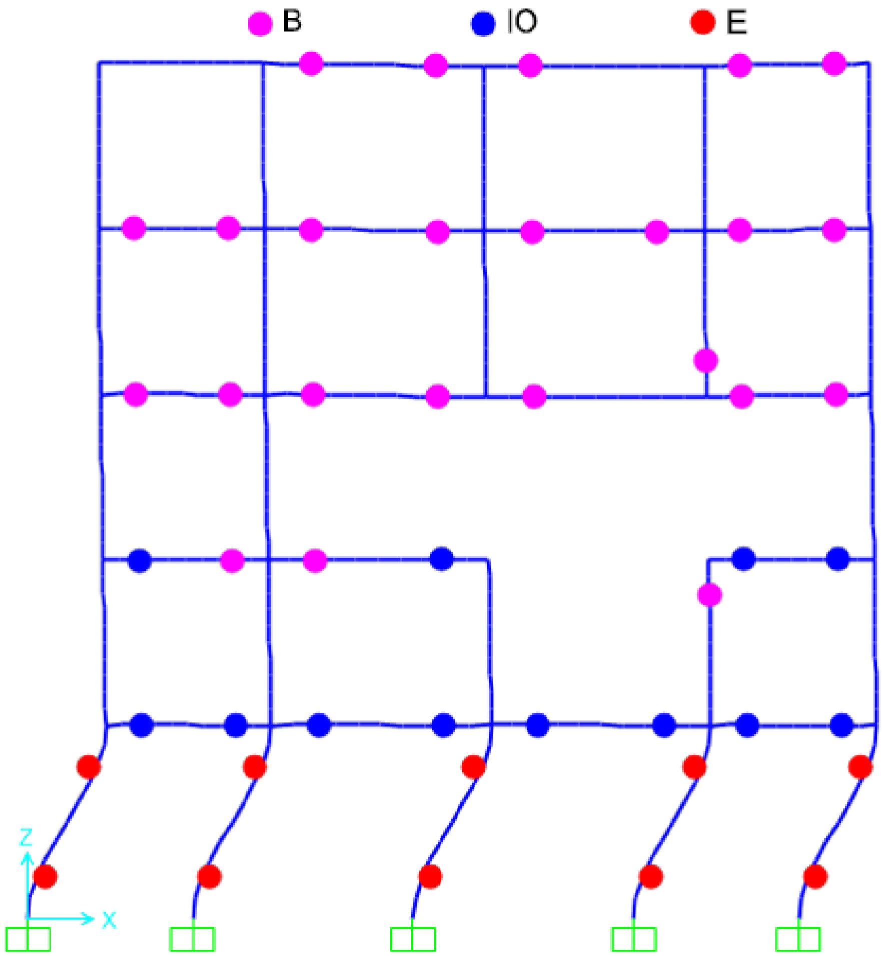


Figure 5.16: Plastic Deformations After Columns Loss (2D)

5.2.2.1 Results of the Modeling Evaluation

The outcome of the simulation study comparing the results with the current reality and the resulting deformations in the structure as a result of the initial damage to the structure is as follows:

- The modeling indicates that, although the source of the explosion is near the structure and the structure would not collapse. The explosion destroyed the middle columns. An additional analysis of the structure was carried out without the slab and columns destroyed by the explosion. So, conclude that there has been a redistribution of the load to other elements and change in the distribution loads led to deflection moments and shear forces at points 1 and 4 as a result of elements inability to withstand these stresses.

- The increase in the axial forces applied to the columns of the second and lower floors from the damage and the collapse indicator started to appear in the columns due to pressure load.
- The occurrence of the large deformations, which leads to cracks expansion.
- There is an extensive plastic deformation in some elements and these elements need for subsequent repair or replacement before they may be re-used.

Chapter 6

CONCLUSION

Evaluation is knowing why certain members were affected while the other members were significantly undamaged, and establish alternative repair strategies or recommend demolition and rebuilding in case the damage is so big that it is difficult to restore any process. Reference records concerning the original building should be collected as far as is available. The collected information must be checked using the real structure to ensure the system is constructed according to that information, if knowledge is not available, field measurements must be taken to determine the conditions for the original building. It is important to inspect each structural component and to detect damage or failure. Cracks width, slotted areas, broken reinforcements and unreasonable distorted members should be reported and any residual anomalies or cracking, whether caused by an accident or not, should be acknowledged and taken into account in the risk treatment proposals. The actual conditions of construction materials can be measured, the residual strength of the damaged parts can be tested on-site using non-destructive techniques. Basic sampling provides more accurate information on the site and accurate measuring for modeling evaluation. However, when the damage is extensive, a greater number of samples must be taken and inspected by a professional petrographic specialist to determine the severity of the fracture, the physical chemical changes and the lack of bonding between the cement matrix and the reinforced steel.

The findings of the visual and modeling procedures are used to determine the severity of the damage to each structural part. And the aim of the modeling analysis of the structure elements exposed to blast load is to check their demanded ductility and compare it to the available ones. This means that non-liner analysis is necessary and simple plastic hinge behavior is satisfactory.

The followings are definitions which were commonly used in earthquake-affected structures.

-Minor damage: minor cracking without significant permanent deformation of the structural feature. This is not considered a concern for reinforced concrete parts, but can contribute to undesirable defects in the building walls.

- Medium damage: significant cracking with visible permanent deformation of the structural part. Structural stability and load capacity may be decreased and any overload can later result in significant damage or breakdown.

- Major damage: systemic damage or loss of materials with significant local or complete deformation. “The strength and stiffness of the unit or structure are reduced to extremely low levels, and failure under dead loads is possible due to general system instability”.

It has been shown that the effects of blast loading can be taken into account in the structural design using the available literature.

Available structural analysis software may be used for design purposes, although further analysis should be geared towards an understanding of the phenomenon of blast damage assessments, thus, a complete picture of the explosion impact on the structure can be developed, as well as a further study should be geared towards a repairing strategy for damaged structures.

Table 6.1 represents visual inspection form concluded form this study to facilitate the reporting of the structure details and significant damage in the structural elements, that can be measured by visual inspection to classify the damage level and structure condition.

Table 6.1: Building Evaluation Form

EASTERN MEDITERRANEAN UNIVERSITY DEPARTMENT OF CIVIL ENGINEERING			
BUILDING EVALUATION FORM			
Engineer:		Department:	
Building's Location			
Building's Number:	Street:	Area:	City:
Created Date:			
Special info:			
Type of Structure			
Residential:		Commercial:	
Industrial:		Governmental:	
Construction Material			
Reinforced Concrete	Steel	Others	
Area			
Total Area:		Number of stories:	
Damaged Area:		No. of damaged stories:	
Surrounding Area			
City Center	Sea Side	Jungles	Desert
Surrounding Buildings			
From 3 Sides	From 2 Sides	From 1 Side	There is no

Notes of the Visual Evaluation		
Whole Structure		
There's an incline in the building:	Direction:	Its Amount:
Distance from the neighborhood buildings:		Its Amount
Exposed to Fire:		Burn percentage %
Cracks in the Whole Structure		
Horizontal and Vertical Cracks between the structural elements (slabs, beams and columns)	Location:	Width and Depth (mm):
Diagonal Cracks in the Walls:		
Diagonal Cracks around the Doors and Windows:		
Wide horizontal cracks in the Structure:		
Cracks in the Columns		
No. and Type of the Cracks:		
Cracks in the beams		
No. and Type of the Cracks:		

Structure condition according to five classifications of the engineering risk	
1	The Structure condition is good
2	The Structure condition meets the requirement (acceptable)
3	The Structure condition meets the requirement in limited way (unacceptable)
4	The Structure condition does not meet the requirement (unacceptable)
5	The Structure is in breakdown (out of service)
Notes:	
Decision:	
ENGINEER:	Signature:

REFERENCES

ACI 318-14. (2014). ACI 318-14 - building code requirements for structural concrete. In *American Concrete Institute*.

Ahmad, S., Taseer, M., & Pervaiz, H. (2012). Effects of Impulsive Loading on Reinforced Concrete Structures. *Technical Journal, University of Engineering and Technology Taxila, Vibration Analysis Issue*, *1*, 8–22.

ASCE. (2017). Minimum design loads and associated criteria for buildings and other structures. In *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. American Society of Civil Engineers. https://doi.org/10.1061/9780784414248

ATC 1996. (n.d.). *ATC-40 seismic evaluation and retrofit of concrete buildings by APPLIED TECHNOLOGY COUNCIL (z-lib.org)*.

Diamantidis, D., & Bazzurro, P. (2007). Safety acceptance criteria for existing structures. *Special Workshop on Risk Acceptance and Risk Communication*, 10.

Ellingwood, B. R. (2005). Risk-informed condition assessment of civil infrastructure: state of practice and research issues. *Structure and Infrastructure Engineering*, *1*(1), 7–18. https://doi.org/10.1080/15732470412331289341

Fédération internationale du béton. (2003). *Monitoring and Safety Evaluation of*

Existing Concrete Structures. International Federation for Structural Concrete, ©2003.

FEMA. (2018). FEMA P-58-1: Seismic Performance Assessment of Buildings. Volume 1 – Methodology. *Fema P-58*, *1*(December 2018), 340.

Gantes, C. J., & Pnevmatikos, N. G. (2004). Elastic-plastic response spectra for exponential blast loading. *International Journal of Impact Engineering*, *30*(3), 323–343. https://doi.org/10.1016/S0734-743X(03)00077-0

Hamdia, K. M. A. (2010). Expert system for structural evaluation of reinforced concrete buildings in Gaza strip using fuzzy logic. *Expert System for Structural Evaluation of …*, 92.

Hussein, A. T. (2010). Non-linear Analysis of SDOF System Under Blast Load. *European Journal of Scientific Research*, *45*(3), 430–437.

IEBC. (2009). International existing building code. *International Code Council*.

ISO 13822. (2010). *Bases for design of structures - Assessment of existing structures* (Vol. 13822).

Kim, Y. M., Kim, C. K., & Hong, S. G. (2006). Fuzzy based state assessment for reinforced concrete building structures. *Engineering Structures*, *28*(9), 1286–1297. https://doi.org/10.1016/j.engstruct.2005.12.011

Luccioni, B. M., Ambrosini, R. D., & Danesi, R. F. (2004). Analysis of Building Collapse Under Blast Loads. *Engineering Structures*, *26*(1), 63–71. https://doi.org/10.1016/j.engstruct.2003.08.011

Magnusson, J. (2007). Structural concrete elements subjected to air blast loading. *Licenciate Thesis, Stocholm*, 96. https://doi.org/10.1017/CBO9781107415324.004

Momeni, M., Hadianfard, M. A., Bedon, C., & Baghlani, A. (2019). Numerical damage evaluation assessment of blast loaded steel columns with similar section properties. *Structures*, *20*(March), 189–203. https://doi.org/10.1016/j.istruc.2019.04.002

NEHRP. (1997). NEHRP commentary on the guidelines for the seismic rehabilitation of buildings. *Federal Emergency Management Agency, Washington, DC, Developed by the Applied Technology Council*, *October*.

Ngo, T., Mendis, P., Gupta, A., & Ramsay, J. (2007). Blast loading and blast effects on structures-An overview. *EJSE Special Issue: Loading on Structures*, 16. https://doi.org/10.4028/www.scientific.net/AMM.94-96.77

Nor, N. M., Musa, M. Z., Ismail, N., Yusof, M. A., & Husen, H. (2010). Damage Evaluation Procedure for Building Subjected to Blast Impact. *European Journal of Scientific Research, 39*(3), 326–335.

Pepenar, I. (2009). Damage evaluation of reinforced concrete structures in aggressive environments : Investigation and diagnosis Résumé Keywords. *Actes Des Journées Scientifiques Du LCPC, 803-806*, 1–4.

Ross, T. J., Sorensen, H. C., ASCE, S. J. S., & Carson, J. M. (1991). *Expert system for structural damage assessment*. *4*(4), 327–348.

Schueremans, L., & Van Gemert, D. (2004). Assessing the safety of existing structures: Reliability based assessment framework, examples and application. *Journal of Civil Engineering and Management*, *10*(2), 131–141. https://doi.org/10.1080/13923730.2004.9636297

SEAOC. (1995). Seismic Design Recommendations. *Structural Engineers Association of California*, *September*, 296.

Shepherd, J. E. (2009). Explosion Effects. *Explosion*, *July*, 160.

Singla, S., Singla, P., & Singla, A. (2015). Computation of Blast Loading for a Multi Storeyed Framed Building. *International Journal of Research in Engineering and Technology*, *04*(02), 759–766. https://doi.org/10.15623/ijret.2015.0402105

Stochino, F. (2016). RC beams under blast load: reliability and sensitivity analysis. *Engineering Failure Analysis*, *66*(May 2016), 544–565. https://doi.org/10.1016/j.engfailanal.2016.05.003

Vrouwenvelder, T. 1997. (1997). The JCSS probabilistic model code. *Structural Safety*, *19*(3), 245–251. https://doi.org/10.1016/S0167-4730(97)00008-8

Wakchaure, M. . (2013). Comparison of Maximum Stress distribution of Long & Short Side Column due to Blast Loading. *Ijmer*, *3*(4), 1988–1993. http://www.ijmer.com/papers/Vol3_Issue4/AT3419881993.pdf

Yap, S. L., & Li, B. (2012). Experimental Investigation of Reinforced Concrete Exterior Beam-Column Subassemblages for Progressive Collapse. *ACI Structural Journal*, *109*(4), 581–583.