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Establishing A forensic Framework for Buildings in Gaza Strip: Reinforced Concrete Structures as a case study

إنشاء إطار قانوني هندسي للمباني في قطاع غزة: المنشات الخرسانية كحالة دراسية

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ABSTRACT

This study looks at the relationship between civil engineering discipline and associated legislation deemed essential to carry out the former's practices. The literature reviewed, as sketched in subsequent pages of this thesis, for this purpose show a serious lack in examining this relationship. In other words, there is not yet an universal forensic framework used for the case of concrete buildings with legal aspects of failures. Such a framework is necessary to outline most legal guidelines necessary to conduct an investigation of failure's causes occurred in the construction process, or arrive at the legal responsibilities that stand behind such failures. Hence, there is a significant gap in knowledge in this respect.

This study seeks fulfilling this gap by suggesting a forensic framework in an effort to approach legal issues tied to the construction process of concrete buildings, with the Gaza Strip as a particular case. The framework accordingly consists of five stages, each comprises steps that show the events inherited in a variety of tasks. The methodology adopted therefore uses three failure case studies; one is in the Gaza Strip whilst the other two are international, which serves validating the forensic framework, established for civil engineering cases within the Gaza Strip while comparing the latter to other existed frameworks.

A key finding that emerge in this study suggests that the proposed framework includes identification of all types of collapses and failures within concrete buildings as well as shedding light on major and/or minor responsibilities of the failures. This study also argues that this framework could be used to other cases of similar legal conditions.

ملخص البحث:

تبحث هذه الدراسة في العلاقة بين نظام وقواعد الهندسة المدنية مع التشريعات والقوانين ذات الصلة التي تعتبر ضرورية لتنفيذ الإنشاءات ، كما ذكرت المراجع العلمية من خلال محتويات هذه الدراسة أن هناك نقص في دراسة هذه العلاقة ، بمعنى آخر لا يوجد هناك إطار قانوني هندسي للمباني الخرسانية مرتبطة بالاعتبارات القانونية للانهيارات والفشل. مثل هذا الإطار لابد من تحديد مبادئ توجيهية أكثر قانونية لإجراء التحقيق في أسباب الفشل والانهيارات في عملية الإنشاء أو الوصول إلى المسئوليات القانونية التي تقف وراء مثل هذه الإخفاقات، وبالتالي هناك فجوة كبيرة في المعرفة في هذا الصدد.

تسعى هذه الدراسة لسد الفجوة المذكورة عن طريق اقتراح إطار قانوني هندسي لربط الجانب القانوني بالجانب الإنشائي للمباني الخرسانية في قطاع غزة. يتكون الإطار المقترح من خمسة مراحل مكونة من عدة خطوات ضمن مجموعة متنوعة من المهام. وقد اعتمدت منهجية البحث علي استخدام ثلاثة حالات دراسية واحدة من قطاع غزة وحالتين دولتين للتحقق من فعالية الإطار لاستخدامه بقطاع غزة وكذلك مقارنة الإطار مع غيره من الأطر الموجودة.

كانت النتائج الرئيسية التي تظهر في هذه الدراسة تشير إلى أن الإطار المقترح يشمل تحديد جميع أنواع الانهيارات والفشل داخل المباني الخرسانية وكذلك تسليط الضوء علي المسئوليات الرئيسية والثانوية لمسببي الفشل. هذه الدراسة تجادل استخدام هذا الإطار لحالات مشابهة في الجانب القانوني.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Forensic engineering may be interpreted as the application of engineering sciences applied to the investigations of failures and/or performance issues [1]. Accordingly, such engineering is a highly specific field deemed essential to achieve not only expertise but also knowledge of the legal procedures. In this vein, forensic structural and/or civil engineers have the sole role of exercising 'autopsies' upon components and/or full-sized buildings, for example bridges and other engineered constructed facilities/infrastructure in an attempt to shed light on the causes that drive the failures. [1] [2].

From the above perspective, forensic engineering addresses on the one hand how the failures occur, for example, in structures, facilities and other relevant structural systems. On the other, from a legal perspective, forensic engineering could be a fact-finding mission necessary to identify the responsibility that causes the failures [2]. In other words, legal aspect revolves around facts that sharpen its perspective.

In order to neatly investigate the causes that lay the template for a failure, thereby identifying the parties involved and each responsibility, one may argue that forensic engineers are a central theme. This is because they demonstrate not only an understanding of loads, strength and stability, but also expertise of how operating business and practices of the design process and the latter's construction may follow. Key skills emerge which suggest where, when, how, why and by whom causes of failures occur. Briefly, forensic engineers address the question of how to conduct the investigation relevant to each case; they must be also familiar with the investigation approach adopted. Since nearly all structural deficiencies pose claims, aspire disputes and require legal entanglements, forensic engineers need to be aware of the relevant legal process, in addition to knowing beforehand how to effectively deal with attorneys. Hence, it could be argued that depth expertise of the nature and consequences emerged as a result of the loads, in addition to the key features that mark vulnerabilities of the structures, is key, if not the key determinant [2] [3].

1.2 GAZA STRIP: CONTENT AND BACKGROUND

Two main features marking the Gaza Strip. The first is primarily related to the latter's coastal region; that is, the Mediterranean. Precisely, its climate architecture suggests that the reinforced concrete structures in particular are susceptible to aggressive actions due to both relative humidity and a high level of salts existed in areas in proximity to the coast. Notably, aggressive actions contribute to the corrosion of steel reinforcement [12] which in turn lays the template for the damages in existing structures. In addition, the latter may face several defecting conditions, starting from the early design stage to completion. These conditions normally include, for example errors in the design stages, failures in the construction processes, defects in the materials and chemical attacks [11] [12]. The second feature notes that the Gaza Strip remains a military occupied region. As a result, manmade destructions occurs on a regular basis due to Israeli military attacks that either destroy the buildings of concern while at present cause serious defects to existing structures.

To remedy the above problems, local authorities and/or engineering offices have carried out evaluations tied to forensic enquiries, followed by suggesting the causes of failure. Remarkably, each has adopted its own strategy and developed own procedure in an effort to both outline the causes of failure and shed light on which party might be responsible. Yet, the strategies remain at impasse.

Indeed, in accord to findings of the empirical research conducted for this thesis the author argues that there is no well-shaped framework in the Gaza Strip necessary to conduct forensic investigation associated with reinforced concrete structures. This is primarily because there is no collective database of the damages occurred in concrete structures in the Gaza Strip which explains the causes and identifies the types of failures. In addition, as analysis of this thesis suggests, no particular guidelines are yet available which have at their heart highlighting the responsibilities that cause these damages. A significant gap in knowledge emerges.

This study attempts to fill this gap by, for example, examining available case studies of relevance, thereby classifying the damages occurred in concrete buildings and identifying the legal aspects of failure. Collectively, The attempt contributes to a forensic framework to be applied in the Gaza Strip.

1.3 STRUCTURE OF THIS STUDY

This section goes on to highlight how this thesis has been developed. It starts by narrating as to why this study has been conducted, followed by discussing the objectives, then shedding light on the adopted research methodology and finally addressing how the data was collected and analyzed necessary to arrive and interpret the findings.

1.3.1 Research Importance

This study is concerned with arriving at a forensic framework deemed essential for evaluating the damage occurred in existing reinforced concrete structures in the Gaza Strip. This framework will ease a golden option to classify these damages while seeking to identify their causes and outline the major and minor responsibilities. Briefly, a major contribution of this study concerns a forensic framework to be applied in the Gaza Strip.

1.3.2 Aims and Objectives

The aims of this study are two-pronged aspects. The first suggests a forensic framework while the second offers broad guidelines relevant to the legal aspects. Accordingly, the specific objectives of this study are as sketched below:

1. Identifying and analyzing the modes of failure in reinforced concrete buildings;
2. Obtaining the relevant legal aspects for failure in building construction and individual responsibilities;
3. Reviewing and identifying the suitable damage assessment system for reinforced concrete building in the Gaza Strip;
4. Establishing a forensic framework for failure in reinforced concrete building in the Gaza Strip; and

5. Validating the proposed framework through the lens of the case studies.

1.3.3 Research Methodology

The objective of this study has been scored by adopting the following steps of data collection:

1.3.3.1 Secondary Sources

Various publications, for example books, technical papers and reports, were critically reviewed for this study to identify the investigation methods and causes of the failure for damages occurred in existing concrete structures. The implication of these studies on the prevailing conditions in Gaza Strip was considered.

1.3.3.2 Gathering Information

Several institutions and consulting firms existed in the Gaza Strip, for example The Association of Engineers, Islamic University Soil and Materials Laboratory, The Association of Engineers Materials Testing Laboratory, and selected engineering consulting firms, were approached, followed by conducting interviews with arbitration center. The primary concern of these interviews sought addressing the strategies adopted to remedy the damages occurred to existing structure in the Gaza Strip suggesting that there is yet no available framework.

1.3.3.3 Data Analysis

Information gathered in this study was analyzed to classify the causes and structure severity.

1.3.3.4 Establishing A Forensic Framework

Based on the available data and according to international standards and guidelines, a forensic framework has been developed for use in the Gaza Strip.

1.3.3.5 Verification of the Developed Framework

The framework adopted in the Gaza Strip was verified by applying several cases equipped with varying levels and damage types of the failure.

1.3.3.6 Conclusion and Recommendation

To the end of this study, conclusions are formulated coupled with recommendations being made which point out some remarks on how to fulfill the significant gap in knowledge, as sketched previously.

1.4 THESIS ORGANIZATION

In an attempt to fulfill its aims and objectives, this thesis is comprised of seven chapters as follows:

Chapter 1 :Introduction

This chapter gives some background information to types of the failure in existing structures, the Gaza Strip particularity; its location, environmental conditions, aggressive actions and background about the forensic investigation practice in Gaza strip. Also, this chapter describes the research importance, aims, objectives and methodology adopted.

Chapter 2: Fundamental to Investigation in Forensic Engineering

This chapter gives some information about goals of forensic engineering investigation. Qualification of forensic engineer, causes of structural failure are of key concern. Modes of the failure and general investigation process are also described.

Chapter 3: Deterioration and Defects in Concrete Structures

This chapter includes a literature review on defects, causes and types, in addition to shedding light on some damaged concrete structures, illustrated to exemplify.

Chapter 4: Legal Aspects for Reinforced Concrete Structures

In this chapter, a general description illustrates the forms of lawful responsibilities, including laws of the Egyptians, Algerians and the Palestinians and the types of contracts adopted in construction.

Chapter 5: Developing a Forensic Framework

This chapter presents types of damages, and the current conditions in Gaza strip, a forensic approach was developed and tested to be used in the Gaza strip. This chapter also gives a detailed description of the proposed approach, visual inspection, site visits, initial failure hypothesis, tests and legal responsibilities.

Chapter 6: Verification of the developed Forensic Framework

This chapter is concerned with the application of the proposed framework on three selected case studies. The latter show different types of damage. A comparison is offered which helps verifying the relevance of the framework for prevailing conditions in the Gaza Strip.

Chapter 7: Conclusions and Recommendations

This chapter includes the concluded remarks, main conclusions and recommendations drawn from this study.

CHAPTER 2

INVESTIGATION FUNDAMENTAL IN FORENSIC ENGINEERING

2.1 INTRODUCTION

One notable observation is that the field of Forensic engineering has rapidly evolved over the time. Indeed, with the prevalence of liability lawsuits in late nineteen century, forensic engineering has ever since served to help identify culpability, widely spread in the courts. Hence, Forensic engineering appears to be about the application of construction rights that adopt in response certain methodologies in an effort to answer factual questions [1]. The questions remedy issues related to accidents, crimes, catastrophic events, degradation of property and various types of failures. Forensic engineering is similar in its engineering methodologies employed to failure and root cause analyses. “Failure analysis” has at its core addressing how a specific part or component of structure has failed. The analysis seeks to answer the question through material selection, design, methods of the production, in addition to mechanics of the failure. The forensic engineer addresses legal problems of the construction. [1] [2].

Activities included in forensic engineering range from physical and/or technical causes of the accidents/failures, preparation of the reports to presentation of the testimony/advisory opinions [2]. The activities assist in approaching appropriate resolution of relevance to the disputes in concern. The forensic engineer may in this respect be responsible for seeking a response to the question who is behind accident or failure of construction. On the other hand, “root cause analysis” emphasizes the managerial aspects of failures [3]. The term is tied to analyzing system failures, rather than examining the failure of specific part of structure and how procedures and/or managerial techniques could be improved in an attempt to prevent construction's problems from reoccurring. Root cause analysis is often used in association with large systems, for example power plants, construction projects and manufacturing facilities, where there is a strong emphasis placed on safety and quality assurance to be realized through the lens of formalized procedures [2].

The modifier labeled 'forensic' typically addresses the question how the occurred event of failure will closely weave together the law, courts, adversarial or public debates and, eventually, a disclosure. Forensic engineering is said to be associated with a specific scope [1], for example analysis of failure or being broad in scope, including for example, but not limited to, a root-cause analysis. The nature of the dispute is a central theme. To establish a robust template for analysis, a forensic engineer heavily relies upon the physical evidence revealed at the scene, verifiable facts and upon well-proven scientific principles [3]. Then he/she applies well-known scientific methodologies in an effort to explain the physical evidence of failure. The analysis commonly requires the simultaneous application of several scientific disciplines. Not surprisingly, therefore, the practice of Forensic engineering is interdisciplinary in nature.

2.2 GOALS OF FORENSIC ENGINEERING INVESTIGATION

In general, the goals [4] of investigation in forensic engineering can be summarized as follow:

1- Determine the causes that have led to failure of the structures and buildings;
2- A comparison statement made in accord to witnesses or injured parties which is supported by a physical evidence;
3- Ascertain whether an illegal or improper activity was causative; and finally
4- Assess the damage caused to material, products or structures and in response evaluate a repair estimate.

2.3 QUALIFICATIONS OF A FORENSIC ENGINEER

The particular technical skill of a forensic engineer varies considerably in accord to the discipline [3]. Nevertheless, a structural forensic engineer is mostly in need of technical skill in an effort to help him/her to arrive at the causes of failure and who is responsible for this failure. Generally, personal and professional characteristics remain a must for all forensic engineer disciplines so that a successful forensic practice could be established.

2.3.1 Technical Competency

Competency is a flagship in civil engineering discipline which is accumulated as a result of proper education and extensive experience [3]. A professional Engineering license is accordingly desirable so that a forensic engineer could qualify for appearing in courtroom testimony. Forensic engineers equipped with rich professional background, including many years of successful engineering practice, sound to be more effective than others in a courtroom testimony. Yet, those who show less practical experience remain effective members of the investigative support team.

2.3.2 Knowledge of legal Procedures

A forensic engineer must have a working knowledge of legal procedures and the related vocabulary. The vocabulary adopted in litigation is rather specific to the extent that less familiarity with this vocabulary and its use results in irreparable damage to an otherwise sound presentation [3]. Similarly, written communications or reports, if prepared or revealed at an inappropriate time, can inadvertently affect litigation.

2.3.3 Detective skills

A forensic engineer, playing the role of an investigator, needs to possess particular detective skill. For example, diligence must be exercised in collecting pertinent facts both from the field and the documents. The quantity and reliability of available data vary considerably in line with each case and also with each discipline. The evidence may nevertheless be limited to police reports, photographs and written records of the eyewitness statements. Notably, collected data will be always incomplete and, in some cases, redundant. Redundant evidence is always helpful because it enables the forensic engineer to double-check/verify the conclusions being reached. However, conflicts remain anchored in redundant data that must be mediated.

An important aspect of data collection is paying sufficient attention to holding onto protecting the evidence. Note that physical evidence must be preserved at all costs. Failure to maintain the evidence, even in cases of minor alterations, could profoundly have an impact on the outcome of the investigation or, better stated, the results of related litigation. Timing is a crucial factor deemed essential to satisfy the collection of reliable data. The forensic engineer is in this regard required to be as early as possible at the accident site. This is because evidence could in some cases vanish immediately following, for example, a fire and industrial accidents or a major structural collapse during the rescue and cleanup operations.

The importance of detective skill, as opposed to design skill, cannot be underestimated [3]. Hence, one may argue that a good design professional may not be necessarily a good forensic expert. This is because the designer is familiar with not only codes of conduct and therefore the standards invested to prevent failure but also with the process necessary to generate alternative concepts that directly respond to given constraints.

2.3.4 Oral and written communication skill

During the investigation, the media news may have the opportunity to interview the forensic engineer. In this vein, contacts made with the media should be viewed from the perspective of restoring public confidence, in addition to showing a professional concern. Needless to say, this can be accomplished without announcing premature specific statements, if the forensic engineer communicates carefully and articulately.

Oral communication skill is therefore a prerequisite necessary to make an effective testimony in the courtroom or in the public hearings. In fulfilling this aim, the forensic engineer plays the role of an educator [3], explaining complex technical issues in language that is quite understandable to lay persons equipped with no technical background. The ability to reinforce simple examples and clear language expressions in response to complex phenomena is therefore essential because it largely improves the credibility of the eye witness.

2.3.5 Other Skills

Familiarity with the fields of psychology and sociology is important and helpful in the forensic engineering. Photographic skill is useful. Often the forensic engineer retains consultants, for example imaging experts or human performance specialists, in an attempt to provide specialized skills. Recognition of the need for particular specialized consultants is an important characteristic marked the competent investigator.

2.3.6 Personal Characteristics

Perhaps, the most important characteristic that marks a competent forensic engineering is a high-ethical standard [3]. Accordingly, the forensic engineer is in a position to adversely affect the professional and personal reputations of all parties involved. The position must be taken lightly that is, the forensic engineer must be able to maintain objectivity and impartiality in seeking the truth, in the face of constant pressures to take an emotional or advocacy position. More importantly, the forensic engineer should be able to enjoy working with others in a tem. This is because the forensic engineer is in the position to coordinate a team of investigators in a constant search for the right investigation.

2.4 CLARIFYING THE FAILURE

The term labeled structural failure has many different meanings [5]. A 'failure' is tied to the condition, or rather the fact, that lays the template for not achieving the desired end whilst structural refers to something built, for example a building or a bridge.

A failure can be clarified as unacceptable difference that occurs between the expected and observed performances [1]. Accordingly, while noting that the definition is broad in nature it includes problems anchored in service ability, for example annoying vibrations, excessive deformations, premature deterioration of the materials and an inappropriate environmental control systems. For example, in the case of buildings, the most costly problems to be found in recurring performance are those strongly related to building envelope performance.

The structural failure can be categorized as follows [6]:

a) Structural distress: an impairment of the strength and/or the load response of a structure which may limit its effectiveness;

b) Structural failure: it is the incapability of a structural system or component to the extent that it cannot be safely fulfill its actual aim; and
c) Structural collapse: the gross movement of major members or a significant portion of a structural system inherited in the creation of rubble [6], stemming from the breakage of the members themselves coupled with the elements that are supported on their own.

A structural failure therefore sheds light on a generic outline which indicates a problem situation, however, without identifying the level of failure, as sketched above.

2.4.1 Causes of structural failures

Usually, there are multiple reasons that lay behind structural failures. Nevertheless, the causes of failures are classified into two major categories [7]: technical and procedural ones. In this respect, the information on sources of failure is deemed essential before attorneys and forensic engineers adequately address the causes of failures.

Technical causes are on the one hand tied to causes of physical proximate. For example, improper compaction of soil could result in excessive settlement of a foundation. On the other, procedural causes are associated with human errors. These include, for example, communication shortcomings that occur in the design and construction process, causing physical failures to occur. For example, a contactor places the top reinforcing steel too low in slab. Another example of a procedural error is a testing laboratory which fails to check the compaction of the soil.

Claims[8] suggest that failures can be classified into three categories: safety, functional and ancillary. Causes of the failure therefore fall into five deficiencies:

a) Design
b) Construction
c) Material
d) Administrative
e) Maintenance

Other classification of failure causes [9] are:

a) Unpredictable
b) Design
c) Detailing and Drafting
d) Material
e) Workmanship
f) Inspection

Other types of classification note seven categories [3] of errors:

a) Fundamental errors in concept
b) Site selection and site development
c) Program deficiencies
d) Design
e) Construction
f) Material
g) Operation

2.4.2 Modes of Failures

Modes of failure pertain to structures that are similar in the way that they fail. The three most common causes of structural failures are instability, fracture, and elastic buckling [9].

Structural failures occurred on the construction site are often caused by a lack of stability [3]. Analysis of the stability requirements for incomplete structure accordingly presents a challenging problem to the most capable structural engineer. Failure can be caused by the fracture of brittle material: for example cast iron or ductile materials such as structural steel and reinforced concrete. Brittle failures occur suddenly and usually without any warning to the occupants. Steel that is ordinarily ductile becomes brittle under various conditions and fatigue-type loading and very low temperatures exacerbate the situation [9].

Elastic buckling takes place within, the elastic range of material. When long, slender columns are compressed lengthwise they tend to buckle before the martial is stressed beyond the elastic range. " Braces in temporary constructions, such as cofferdams and trench excavations, are always the first to fail" [9].

2.4.3 Types of Failures

Catastrophic and sub catastrophic failure may be categorized into three types: safety, functional and ancillary [10]. The technical Council on Forensic Engineering of the American Society of Civil Engineers 1989 classifies a failure with respect to the extent and type of damage in to four types: safety, functional, latent, and ancillary.

On the other hand there is another type for classification of failure as construction, service or maintenance failure [9]. Construction failures can occur prior to construction or during construction. Construction error prior to construction are concept and design errors. The statistics show that structural failures during construction often occur as a result of the following three causes:

a) Formwork failure and collapse
b) Inadequate temporary bracing
c) Overloading and impact during construction

Failure resulting from errors during service is usually caused by accidental overloading of floors and roofs and other accidental or international abuses of the structure. Accidental overloading may be the result of high winds from hurricanes.
Abuse, or misuse of the structure, may be in the form of unusually heavy loads, impacts loads and vibration loads.

2.5 ENGINEERING INVESTIGATION OF STRUCTURAL FAILURE

Investigation of the structural failure is conducted for a variety of purposes [4]. Most commonly, when a structure collapses, there is litigation involved. In this vein, the forensic engineer is retained by those who hold into a defendant interest in an attempt to determine the deficiencies and who is responsible. For the forensic engineer, a particular challenge falls within the pressure tied to compromise his/her objectivity and impartiality, when answering a client in reference to a particular bias. For failure less catastrophic than a collapse, the forensic engineer could retained by the owner or the manager of a building or, in some cases, the insurance company in an effort to diagnose structural performance and in turn address how litigation may not be anticipated. Notably, an investigation could be commissioned, simply, seeking to inform the general public or the government agency about errors occurred in the construction and who is responsible.

2.5.1 Project initiation

It requires establishing a minimum preliminary objective [2], in addition to the scope of work, thereby shedding light on conflicts of interest and executing a contract agreement that lays the template for an investigative plan.

2.5.2 Establishing the Investigation Team

A comprehensive list, including many specialists, which forms the basis for the principal investigator (PI) , these specialists such as field testing, concrete design, hydraulics and soil mechanics. The qualities required for these specialists are generally as cited above. The forensic engineer should have in this respect pre established relationships with specialty consultants in order to call them on short notice when the need arises [2].

2.5.3 General Investigation Process

There are some common steps in the investigative process helping forensic engineer to answer the questions related to causes of failure, these steps are summarized as follow:

- Commission of forensic engineer by client
- Definition of objective of investigation
- Collection of background information
- Preliminary document review
- Initial reconnaissance site visit
- Eyewitness interviews

- Formulation of investigative plan
- Formation of project team
- Comprehensive collection of documents
- Document review
- Site investigation
- Sample collection
- Theoretical analyses
- Laboratory analyses
- Development of failure hypotheses, analysis of data, synthesis of information, and formation of conclusions
- Determination of procedural responsibilities for failures
- Report writing

2.5.3.1 Field of Investigation

It involves making observation and conducting measurements on varying scales in an attempt to document the existing conditions, removing samples, interviewing eye witnesses and performance in field tests [2].

2.5.3.2 Document Review

Project documents are key to understanding not only how the structure was built but also how it was maintained and modified over time; without such documents the job is almost impossible for a complex project. Whenever possible, the investigator should obtain and review at least the most fundamental design documents prior to the initial site investigation. Project documents are also key when the forensic engineer is called upon to opine on the procedural causes of the failure in that the documents provide insight into the actions of those responsible for the design, construction, and operation of the facility[2].

2.5.3.3 Development and analysis of failure hypotheses

The most common mistake made by novice and experienced investigators alike is failure to consider all possible failure hypotheses. This is a pitfall for both the inexperienced investigator, who may miss a key action, and the experienced investigator, who may jump to a conclusion, thinking he's seen it before. All probable hypotheses must be developed and systematically analyzed until they can be either proved or disproved. Key in developing failure hypotheses is to study carefully the configuration of the debris after the failure, and then to imagine all the different failure sequences that the structure could have undergone in order to arrive at its final configuration [2].

2.5.3.4 Advancement of failure hypotheses

Over the course of the investigation, failure hypotheses are continuously tested against the facts collected from field investigation, documents, testing, and analysis. Some hypotheses may be disproved and dropped, while new ones may be advanced. It is generally advisable to assemble the investigative team shortly after the initial site investigation for a brainstorming session on failure hypotheses[3].

2.5.3.5 Laboratory analysis

Laboratory test [2] is performed to examine the material or structural component. Accordingly, it also involves both material test and component testing.

2.5.3.6 Structural analysis

Calculations are almost required to determine both the load acting on the structure and the structures resistance. In many cases, simple hand calculations suffice. Nevertheless, it is necessary to rely upon computer methods, such as finite element or finite difference techniques [2].

2.5.3.7 Determine the cause of failure

Initially, it is important to identify most possible failure scenarios. Therefore, facts gathered from the observations, documents, analysis and testing eliminate unlikely scenarios while highlighting the likelihood of all remaining scenarios. Knowledge gleaned from this process will lead to further analysis and testing that will result in reducing the list of possible failure scenarios. The aim is to converge on a small set of factors that are the most likely technical causes of the collapse.

Eventually, the testing and analysis carried out will assist the investigation team touch upon the cause of failure. Theories of failure are often developed on the basis of prior experience with similar failures despite the team members being almost flexible in relation to the causes or combination that has not been experienced yet [2].

2.5.3.8 Reports

The final outcome of the investigation process leads to a report that documents the failure. Report is accordingly organized so that proven facts, stemming from a variety of sources, are laid out at first glance. The whole report presents a convincing and logical argument based on facts, right from the discussion to the conclusion. The causal relationship intersecting between identified deficiencies in design, construction and maintenance must be shown in the report. For example, a typical outline for reporting the structural investigations is shown below [2].

Summary

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- Laboratory tests
- Results of calculations
- Discussion of field investigation, laboratory tests, and results of calculations
- Conclusions
- Recommendations.

2.6 PREVIOUS STUDIES

Sam Brown studied minimizing the risk and improving technology by forensic engineering in his paper titled 'Forensic Engineering: reduction of risk and improving technology', published 2007, highlights few possibilities that shows how investigation in forensic engineering may minimize risk, hence, improving technology adopted in great and small products. Generally, it has at its core the inter-relationship that identifies who is responsible for ensuring quality engineered systems, safety and loss prevention, the organizational areas of responsibilities, in addition to casual factors. He uses a pressure system that consists of pipes, vessels, turbines and heat exchanger. An explosion occurred at the plant followed by a series of explosions, causing 1.5 billion dollar loss and 23 deaths, mainly workers, at the facility. Moreover, the paper is concerned with hazards as a result of system failures. The question for addressing is how to determine the probability of hazards, the consequences that follow and the causes that lay behind the risk embedded in personnel and loss prevention.

In response, he starts first by outlining who is responsible for satisfying the quality systems, including for example the designer, manufacturers and uses of the system. Other responsibilities are categorized through indirect or direct influences, for example training, technical association, litigation, government regulators and the organization itself. Secondly, the area of responsibilities generated by one or several organizations is of key concern which result in causes of failure is attached to, for example, material defects, maintenance and inspection. Notably, the factors inherent in a safe system or loss prevention include, for example, costs, risks or warnings. Modes of failure also count which include elastic formation or stress rapture.

C. Gonzalez-Nicieza etal studied the steps necessary in investigation applied in forensic engineering in paper titled 'forensic analysis of a pile foundation failure', published 2010. These steps start from 'background' and 'lab analysis to 'casual factors for the incident'. The damage shows, as a result of artificially lowering the groundwater table, which occurred during the construction of a building situated in the vicinity. This study also seeks to examine the land subsidence, in addition to negative friction experienced by the piles as a result of artificially lowering the groundwater table.

Therefore, one of the first notes tied to the problem highlighted in this paper is the pathologies extended beyond the building block studied as a particular case, given that in the past in this case, some residential buildings in the surrounding area had been badly affected by cracks and major collapses eventually resulted in being demolished. Moreover, within a radius of approximately 300 m facing south–west, the sidewalks showed cracks and major subsidence. Owing to the differential subsidence that happened as a result of the decrease in the groundwater table major cracks follow.

Harry Poulos studied establishing a forensic foundation engineering in his paper titled titled 'A Framework for Forensic Foundation Engineering' , published 2011. He describes a relatively simple framework for investigating the possible causes of foundation failures in a systematic manner. Attention is confined to foundation failures (ultimate failure conditions), although similar principles can be applied to cases involving excessive deformations of the foundation system (serviceability failures).

Cezary Madryas studied the problem of failures of sewerage and water supply system in his paper titled 'Forensic investigations of buried utilities failures in Poland' published 2007. he described typical kinds of damage to pipelines and classified according to reliability theory and their causes. Results of the author's examination of damaged sewerage and water-supply pipelines, including the causes of four failures, are presented. In the conclusion, the principal hazards to failure-free operation of underground infrastructure are indicated.

CHAPTER 3

DETERIORATION AND DEFECTS IN CONCRETE STRUCTURES

3.1 INTRODUCTION

Briefly, concrete has been widely used as a structural material[11] since the 20th century. However, it witnesses deterioration evident from the design stage to the service stage. Deterioration appears as defects that considerably vary from a simple case in most structures to severe and destructive defects, which unfortunately cause excessive collapse. Notably, deterioration of the material reduces the effectiveness of structure. As a result, maintenance will be extensive. To explain, once completing the investigation phase the next step establishes the causes responsible for the damage detected. Since many of the symptoms are caused by more than one mechanism that affects the concrete, it deems essential to understand the basics that underlay the causes of concrete deterioration within structures. In the Gaza Strip, for example, environmental conditions seriously affect concrete buildings which cause propagation of many types of defects, like corrosion of steel reinforcement and deterioration of the concrete. Such a defect usually appears after 15 and/or 20 years which is to a large extent environmentally dependent[13][12]. Moreover, defects are tied to construction and design errors, in addition to poor quality of the concrete. Israeli military intervention occurred late 2009 has caused serious damage to many buildings in the Gaza Strip due to fire attack.

The above findings shed light on the necessity to review the defects reported in the literature; therefore, collecting data – supported by photographs where possible – regarding the most common types of defect occurred in the concrete structures is sought. The forensic engineer is in this respect a tool that easily identifies the defects, detect their causes and eventually report about the conditions that underlay the structure in a scientific method, well-adopted to universal standard.

3.2 CAUSES OF DAMAGES WITHIN BUILDINGS

Damages occurred in buildings existed in the Gaza Strip continue to be of a steadily growing concern. Accurate data on the condition of concrete in these buildings is crucial because such data helps evaluate safety and measure service ability [14]. A basic understanding of the causes to concrete's deficiencies therefore lay the template for performing meaningful evaluations and successful investigations, too. Once the causes are recognized rational decisions follow which have at stake the damages' legal aspects.

Progressive cases of the many categories of damages arise and speed up in certain environments and, in particular, if concrete structure has insufficient cover, or is porous [15]. Various methods could be adopted to classify the causes of defects; for example in accord to causes, types or severity. Usefully, the defects in existing buildings could be classified in accord to one or more of the below categories:

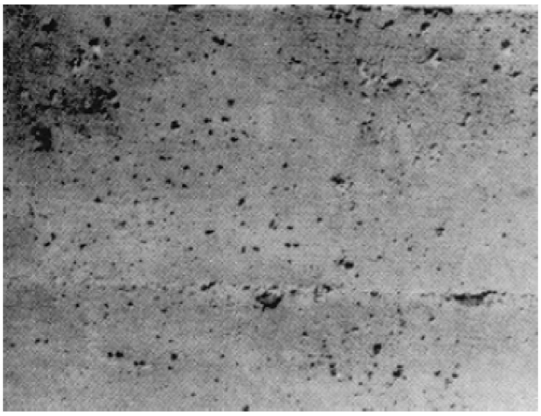
1. Signs of the poor quality, both in the design and at the construction stages, for example wetting and dampness or leakage as well as structural and non structural cracks to be found in the foundation settlements;
2. Physical damage, such as freeze- thaw action, cracking due to thermal movement and shrinkage cracking;
3. Mechanical damage that occurred due to, for example, impact, explosions and abrasion; and
4. Chemical damage that ranges from carbonation, chloride contamination or ingress to alkali- silica reaction.

In what follow, a classification of defects is discussed in accord to their causes.

3.2.1 Damages Caused by Construction Errors

When concrete structure is fresh constructed, some types of the damage's attributable occur due to unsatisfactory construction practice [11]. The damage, in this case, is interlocked to an immediate effect that impacts structural integrity. The damage occurs due to poor construction which is tied to reducing durability manifested in the years thereafter. Notably, practices of the poor construction cause defects that result in both cracking and concrete deterioration. Typical construction faults - that may be found during a visual inspection - include bug holes, evidence of the cold joints, exposed reinforcing steel, honeycombing, irregular surfaces caused by improperly aligned form and a variety of surface defects and irregularities (Fig 3.1). These faults occur as a result of poor workmanship and/or the failure to adopt to universal practice [12].

Fig. 3.1: Construction Faults in Concrete



Bugholes (www.usace.army.mil)

Cold Joints (www.enhance-solutions.com)

Blistering (www.structuraldesign.com.au)

Bad Surface finish(www.enhance-solutions.com)

a) Adding water to concrete

Water is usually added to concrete in one or both of the following circumstances. Firstly, water is mixed with concrete in a delivery truck in an effort to increase slump, thereby decreasing emplacement effort. However, whilst water cement ratio (w/c) of the concrete increases, strength and durability decrease. Such mixing generally results in concrete marked by either lowered strength or reduced durability. In the second case, water is commonly added while finishing the flatwork. This practice leads to scaling, crazing and dusting of the concrete in service.

b) Improper alignment of the formwork

Improper alignments of the formwork lead to the concrete being marked by discontinuities on the surface. Notably, while these discontinuities are unsightly in all circumstances, their occurrence may be more critical in areas that are subjected to a high level of velocity flow inherited in water - where cavitations-erosion may be induced or in lock chambers where the “rubbing” surfaces must be straight .

c) Improper consolidation

Improper consolidation of the concrete results in variety of defects. The most common ones are bug holes, honeycombing and cold joints. “Bugholes” are formed when small pockets of the air or water are trapped facing the forms. A change in the mixture deemed essential to make it less “sticky”, or the use of small vibrators worked near the form, has been used to help eliminate the bug holes. Honeycombing are minimized by inserting the vibrator more frequently than usual. In so doing, the vibrator is as close as possible to the form's face but remarkably without touching the form, thereby a slower withdrawal of the vibrator. Markedly, any or all of these defects make it much easier for any damage-causing mechanism to initiate deterioration of the concrete. Owing to fear a “over consolidation” is used because it justifies the lack of effort needed for consolidating the concrete. More consolidation than needed occurs in a situation in which the consolidation effort causes all of the coarse aggregate. This would help settling to the bottom, while the paste rises to the surface. In this case, one may suggest that a problem of a poorly proportioned concrete is applicable, rather than the case being too much consolidation.

d) Improper curing

Curing is probably the most abused aspect of the concrete occurred at the construction process. Unless concrete is given adequate time to cure, both at proper humidity and temperature, it will not inhere the characteristics expected which are necessary to provide durability. Symptoms of improperly cured concrete show various types of cracking and surface disintegration. In extreme cases, where poor curing leads to failure to achieve anticipated concrete strengths, structural cracking follows.

e) Improper location of reinforcing steel

This section refers to reinforcing steel that is improperly situated, or better stated, is not adequately secured in its proper location. Two general types of problems emerge. One problem shows that steel is not functioning from the structural perspective as anticipated. The result is structural cracking or failure. A particularly prevalent example is the placement of welded wire mesh in the floor slabs. Yet, the mesh ends up on the bottom of the slab which eventually cracks because the steel is not in the proper location. The other problem stems from improperly located or, rather, is tied to reinforcing steel marked by durability. The tendency for the steel to end up near the surface of the concrete is common. As the concrete's cover put over the steel is reduced, corrosion easily emerges.

f) Movement of the formwork

Movement of the structural formwork while the concrete is transformed from a fluid to a rigid material induces cracking and separation within the concrete. A crack on the surface attracts water to enter the concrete's interior. An internal void smoothes freezing, or corrosion, problems, if the void becomes saturated.

g) Premature removal of the shores/reshores

If shores/reshores are removed too soon, the concrete of concern becomes overstressed and therefore cracked. In extreme cases, there may be major failures.

h) Settling of the concrete

During the period concerned with placing and initial setting of the concrete, the heavier components of the concrete settle beneath the influence of gravity. This situation may be aggravated by the use of highly fluid concretes. If any restraint tends to prevent this settling, cracking or separations follows. However, these cracks or separations develop problems associated with corrosion or freezing, if concrete is saturated.

i) Settling of the sub grade

If there is any settling of the sub grade upon the concrete becoming rigid, however, before it gains enough strength to support its own weight, cracking also occurs.

j) Vibration of freshly placed concrete

Most construction sites are subjected to vibration caused by various sources, for example blasting, pile driving and the operation of construction equipment. Freshly placed concrete is vulnerable to weakening of its properties, if subjected to forces which disrupt the concrete matrix during this setting. The vibration limits for the concrete expressed in relation to peak particle velocity (Table 3.1) were established as a result of laboratory and field test programs.

Table 3.1

Vibration Limits for Freshly Placed Concrete[11]

Age of concrete at time of vibration (hr)	Peak Particle Velocity of Ground Vibrations
Up to 3	102mm / sec
3 to 11	38mm / swc
11 to 24	51mm /sec
24 to 48	102mm / sec
Over 48	178mm / sec

k) Improper finishing of the flat work

The most common improper finishing procedures which are essential to the durability of flat work are discussed below, largely depends on the reference.

i. Adding water to the surface

Evidence associated with water being added to the surface indicates the presence of a large paint brush, along with other finishing tools. The brush is dipped in water and the latter is "slung" onto the surface being finished.

ii. Timing of finishing

Operations of the final finishing have to be done upon both the concrete being extracted from its initial set and bleeding has stopped. The waiting period largely depends on the amounts of water, cement and admixtures existed in the mixture. However, one major factor relates to the temperature of the concrete's surface. On a partially shaded slab, the part facing the sun will be usually ready to be completed before the part in the shade.

iii. Adding cement to the surface

This practice is often accomplished in an attempt to dry up the bleed water, thereby allowing the finishing to be proceeded. The result is a thin cement-rich coating that easily crazes/flakes off.

iv. Use of the tamper

A tamper or "jitterbug" is unnecessarily. However, this tool reinforces the coarse aggregate away from the surface; hence, it leads to an easier finishing. This practice, nevertheless, creates a layer of cement-rich mortar surface that could be scaled or crazed. A jitterbug does not fit within a well-designed mixture. If a harsh mixture is accomplished, the judicious' use of a jitterbug is said to be useful .

v. Jointing

The most frequent cause of cracking in flatwork is the incorrect spacing and location of joints as shown in Figure 3.1.

3.2.2 Damages caused by Design Errors

Design errors are classified into two general types [11]. One relates to those resulting from an inadequate structural design. The other is tied to those stemming from insufficient attention to relatively minor design details. Each type is discussed below.

a) Inadequate structural design.

Improper design or inaccurate estimate of imposed loading on structural elements leads to over- stressing the concrete element beyond its capacity. These faults will be manifested in the concrete either by cracking, spalling, or even collapse. If the concrete experiences high compressive stresses then spalling will occur. Similarly if the concrete is exposed to high torsional or shearing stresses then spalling or cracking may occur. High tensile stresses will cause the concrete to crack especially in the area of high stress concentration.

b)Poor design details.

While a structure may be adequately designed to meet loadings and other overall requirements, poor detailing may result in localized concentrations of high stresses in otherwise satisfactory concrete. These high stresses may result in cracking that allows water or chemicals access to the concrete. In other cases, poor design detailing may simply allow water to pond on a structure, resulting in saturated concrete.

3.2.3 Damages caused by physical causes

3.2.3.1 Cracking in plastic concrete

Unexpected cracking of concrete is a frequent cause of complaints. Cracking can be the result of one or a combination of factors such as drying shrinkage, thermal contraction, restraint (external or internal) to shortening, sub-grade settlement, and applied loads. Cracking can be significantly reduced when the causes are taken into account and preventative steps are utilized[13].

a- Plastic shrinkage cracks

Plastic shrinkage cracking as shown in fig. 3.2 occurs when concrete is subjected to a very rapid loss of moisture caused by a combination of factors including air and concrete temperatures, relative humidity, and wind velocity at the surface of the concrete. When moisture evaporates from the surface of freshly placed concrete faster than it is replaced by bleed water, the surface concrete shrinks. Due to the restraint provided by the concrete below the drying surface layer, tensile stresses develop in the weak, stiffening plastic concrete, resulting in shallow cracks of varying depth which may from a random, polygonal pattern, or may appear parallel to one another.

These cracks are often wide at the surface. They range from a few centimeters to meters in length and are spaced from a few centimeters to as much as 3m apart. Plastic shrinkage cracks begin as shallow cracks but can become full-depth cracks[12].

Fig. 3.2: Plastic shrinkage cracks.
(www.cement.org/tech/faq_cracking.asp)

a- Settlement cracks

After initial placement, vibration and finishing, concrete has a tendency to continue to consolidate. During this period, the plastic concrete may be locally restrained by reinforcing steel, a prior concrete placement, or formwork. This local restraint may result in voids and/or cracks adjacent to the restraining element such as shown in Fig. 3.3. settlement cracking increases with increasing bar size, increasing slumb, and decreasing cover. The degree of settlement cracking may be intensified by insufficient vibration or by the use of leaking or highly flexible forms.

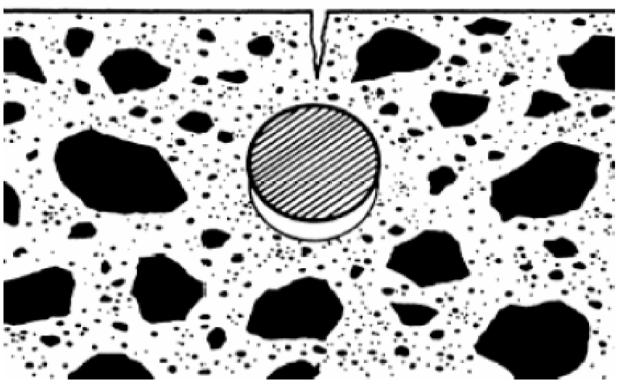


Fig. 3.3: settlement cracks.
(ACI 224.1-R93)

3.2.3.2 Damages in concrete after hardening

a- Drying shrinkage crack

Drying shrinking is caused by the loss of moisture from the cement paste. Concrete tends to expand on wetting, and to shrink on drying. If the shrinkage of concrete could take place without restraint, the concrete would not crack. It is the combination of shrinkage and restraint that causes tensile stresses to develop.

When the tensile strength of concrete is exceed, it will crack. Cracks may propagate at much lower stresses than are required to cause crack initiation. Crazing usually occurs when the surface layer of the concrete has higher water content than the interior concrete. The result is a series of shallow, closely spaced, fine cracks.

Drying shrinkage can be reduced by increasing the amount of aggregate and reducing the water content.

Surface crazing (alligator pattern) on walls and slabs is an example of drying shrinkage on a small scale as shown in fig. 3.4, while improper joint spacing may result in cracks like than shown in fig. 3.5

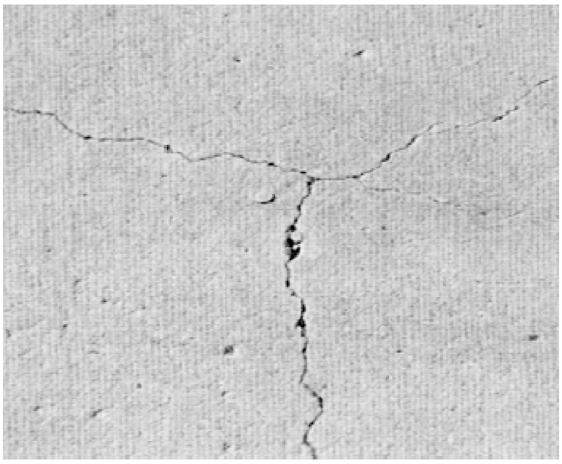


Fig. 3.5 :Drying shrinkage cracks due to improper joint spacing
(ACI 302.1-R04,www.portcement.org)

Fig.3.4: Craze cracks.
(www.praire.com)

b- Damages due to thermal stresses and fire

Temperature differences within a concrete structure result in differential volume changes. When the tensile stresses due to the differential volume changes exceed the tensile strength, concrete will crack. The effects of temperature differentials due to different rates of heat dissipation of the heat of hydration of cement are normally associated with mass concrete(which can include large column, piers, beams, and footing, as well as dams), while temperature differentials due to changes in the ambient temperature can affect any structure. The result may be as a pattern cracking such as shown in fig. 3.6.

As a special case, fire creates high temperature gradients and because of this, the hot surface layer tends to craze, followed by spalling from the cooler interior of the concrete member. The reinforcement may become exposed and the action of the fire accelerate. The extend of damage depends on the temperature reached, loading conditions under fire, and characteristics of the concrete, which includes the quality of concrete and types of aggregates used. Typical fire damage is shown in fig. 3.7

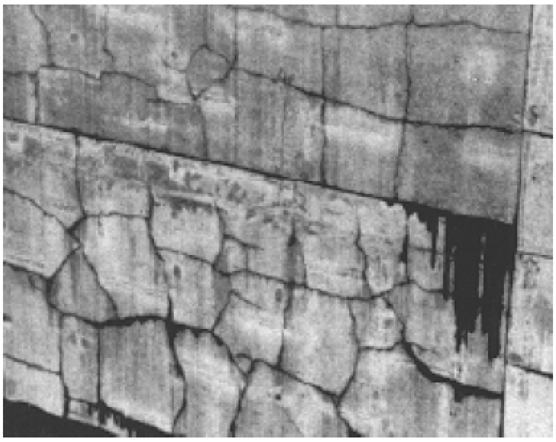


Fig. 3.6:Pattern crack caused by Restrained volume change
(www.usace.army.mil)

Fig.3.7: Typical fire damages

(IUG library building- march)

c- Weathering cracks

The weathering cracks processes that can cause cracking include: Freezing and thawing, Wetting and drying and heating and cooling. Deterioration from freezing and thawing is the most common weather-related physical deterioration. Concrete may be damaged by freezing of water in the paste, in the aggregate, or both. Other weathering processes that may cause cracking in concrete are alternate wetting and drying, and heating and cooling. Both processes produce volume changes that may cause cracking.

3.2.4 Damages caused by chemical reactions

All concrete in service will be subject to chemical and physical changes. A durable concrete is one in which these changes occur at a rate, which does not detrimentally affect its performance within its intended life. Reinforced concrete structures has not proved to be durable due to large number of factors including variations in production, loading conditions in service life, and subsequent attack by the environmental factors.

The main causes of deterioration of concrete structures are briefly explained as follows:

3.2.4.1 Corrosion of reinforcement

Reinforcement corrosion and the subsequent spalling of the cover concrete have been major issues in construction for many years. In theory, embedded steel should not corrode. It is protected against corrosion because of the passivating film which is formed in the alkaline environment produced by cement hydration. Hydration products, give the pore solution of concrete a pH value around 13. However, aggressive agents such as carbon dioxide or chloride ions can destroy this passivating film. Once destroyed, corrosion proceeds with the formation of electrochemical cells on the steel surface. Finally, the corrosion product causes cracking and spalling of the concrete cover. Thus, the corrosion process of steel in concrete can be divided into two stages: initiation and propagation as shown in Fig. 3.8. The initiation stage is determined by the ingress of carbon dioxide or chloride ions into the concrete cover while the propagation stage, or corrosion rate, is dependent on the availability of water and oxygen in the vicinity of the steel reinforcement [16].

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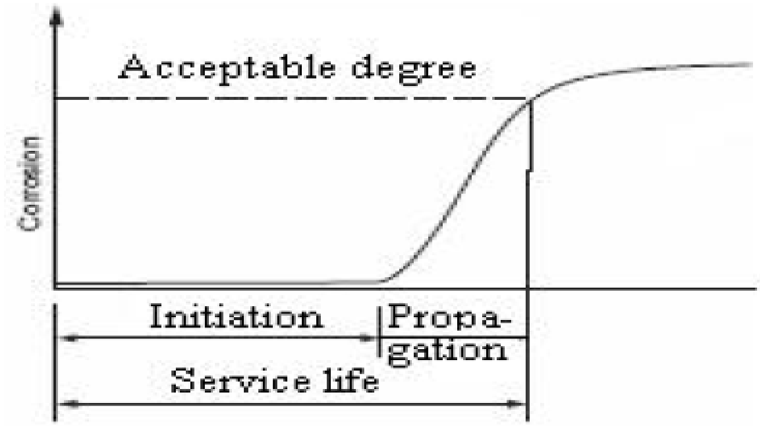


Fig. 3.8: Schematic Diagram of Corrosion Process of Steel in Concrete[16].

Once the embedded steel is depassivated, corrosion proceeds with the formation of electrochemical cells comprising anodic and cathodic regions on the steel surface, with electric current flowing in a loop between the two regions as shown in Fig. 3.9. Corrosion occurs at the anode, where there is ionization and dissolution of the metallic iron to Fe++ . At the cathode, reduction of oxygen occurs. The cathodic reaction consumes electrons and leads to the formation of the OH ions[16].

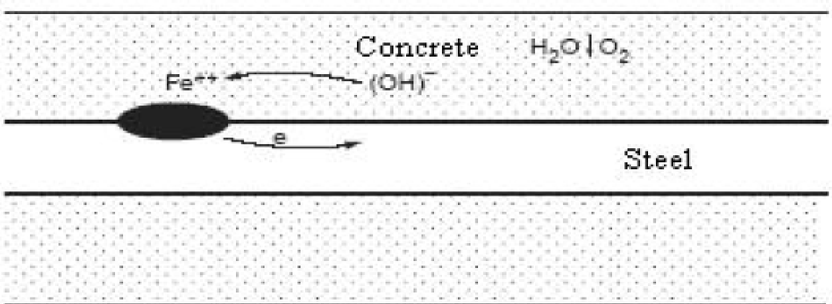


Fig. 3.9: Schematic Representation of Electro-Chemical Reaction[16].

Anode: $Fe \rightarrow Fe^{2+} + 2e^-$

Cathode: $0.5\ O_2 + H_2O + 2e^- \rightarrow 2(OH)^-$

The ions formed at the cathode and anode move in the pore solution of the paste of the concrete and react chemically to produce an iron oxide near the anode, generally known as rust.

It is obvious that for cathodic reaction, and thus corrosion to occur; both oxygen and water are required. In dry concrete with relative humidity less than 60% as in the case of concrete exposed indoors or protected from rain, corrosion of reinforcement may be considered negligible even though carbonation can be substantial. Also Corrosion may also be negligible in water-saturated concrete because of the restriction in oxygen supply[16].

The deterioration of concrete due to corrosion results because the corrosion product (rust) occupies a volume two to six times larger than the original steel it replaces. This increase in volume exerts substantial pressure on the surrounding concrete, causing spalling and delamination of the concrete cover. In practice, initial concerns are cracking and rust stains on the concrete surface. Rust from outer 0.1 to 0.5mm of steel bar is sufficient to cause cracking. However, the reduction in this diameter is generally considered too small to have practical significance on the load-carrying capacity of the reinforced concrete element. As corrosion continues to an advanced stage, reduction in steel cross-section will lead to a decrease in load carrying capacity of the member[16].

3.2.4.2 Carbonation

Carbonation is defined as the process whereby carbon dioxide in air diffuses into concrete, dissolves in the pore solution, and then reacts with the hydroxides, converting them to carbonates with a consequent drop in pH to a value less than nine. Depassivation of steel occurs as pH of the pore solution approaches 11.

In practice, the depth of carbonation can be determined by spraying a phenolphthalein solution onto a freshly broken concrete sample. This colorless solution changes to pinkish purple at pH values greater than about 9.5, indicating un-carbonated concrete. The rate of carbonation is very much moisture dependent. Carbonation of concrete is the highest at relative humidity (RH) between 40 to 70%, but negligible in dry conditions (<25% RH) due to insufficient water to promote the reaction, and at high humidity (>90% RH) because water in pores of cement paste inhibits diffusion.

Compared with tropical environment, concrete exposed to temperate climate like in Gaza Strip are expected to have higher carbonation rates. In practice, vertical surfaces such as building facades carbonate faster than horizontally exposed surfaces like top surface of roof slabs and balconies because horizontal surfaces have a higher frequency and longer duration of wetting.

The carbonation in itself does not cause the deterioration of concrete. In fact, compared to the original concrete, carbonated elements tend to have slightly higher compressive strength and improved permeation properties due to the formation of calcium carbonate with a consequent reduction in the porosity of concrete.

Carbonation is not a concern for un-reinforced concrete elements such as roofing tiles and masonry blocks. Carbonation affects only the length of corrosion initiation stage. For internal structural elements and due to the lack of sufficient moisture to initiate corrosion, concrete remains durable even though carbonation can be substantial. For external elements exposed to the weather, corrosion will occur once the concrete is carbonated close to the reinforcement. Thus, the quality and thickness of the concrete cover are important in controlling the time to initiate corrosion. Codes specify concrete cover and link it to the environmental conditions such as to ensure that carbonation does not reach reinforcement during the life span of the structure. In normal practice and for typical concrete, it may take 20 years or more to carbonate the concrete cover[16].

3.2.4.3 Effects of Chloride

Soluble chlorides present in seawater, ground water or de-icing salts may enter concrete through capillary absorption or diffusion of ions in water. Chlorides may also be present in chemical admixtures and contaminated aggregates or mixing water in the production of concrete. The presence of chlorides in reinforced concrete can be very serious depending on the quality of concrete and its exposure environment. The free chlorides are responsible for the initiation of steel corrosion. Due to various factors, the proportion of free chloride ions in concrete varies from 20% to more than 50% of the total chloride content. For corrosion to be initiated there has to be a minimum level of free chloride concentration at the steel surface. However, threshold values for depassivation are uncertain, with commonly quoted values between 0.1 and 0.4% of free chloride ions by mass of Portland cement.

Buildings and bridges near the coast often suffer severe corrosion problems due to the co-existence of both carbonation and chloride penetration[16].

3.2.4.4 Sulfate Attack

Naturally occurring sulfates of sodium, potassium, calcium, or magnesium can be found in soils, seawater or ground water. Sulfates are also used extensively in industry and as fertilizers. These may cause contamination of the soil and ground water. Sources of sulfate can also be internal, released from the cement during service. Sulfate attack can take one of the following forms:

1. Physical attack due to salt crystallization.
2. External chemical sulfate attack involving reactions between sulfate ions from external sources with compounds from set cement.
3. Internal chemical sulfate attack due to late release of sulfate within the concrete.

In the control of sulfate attack, it is important to use high quality, low permeable concrete. The use of sulfate resisting or blended cement is an added advantage. During service, a good drainage or waterproofing system may be necessary to keep concrete in a relatively dry state and prevent sulfate attack[16].

3.2.4.5 Acid Attack

As with sulfates, acids can be found in soils and ground water. These may be organic in nature resulting from plant decay or dissolved carbon dioxide, or may be derived from industrial wastes, effluents and oxidative weathering of sulfide minerals. Liquids with pH less than 6.5 can attack concrete.

The attack is considered severe at pH of 5.5 and very severe at 4.5. Concrete is held together by alkaline compounds and is therefore not resistant to attack by strong acids. They do not go into complex chemical reactions similar to those in sulfate attack, but simply dissolve the hydrated compounds of the set cement. The ultimate result of sustained attack is the disintegration and destruction of the concrete.

Acid rain, which consists of mainly sulfuric acid and nitric acid, may cause surface weathering of the exposed concrete[16].

3.2.4.6 Seawater

Seawater Concrete exposed to seawater can be subjected to both physical and chemical attacks. Seawater contains a number of dissolved salts with a total salinity of around 3.5% and pH values ranging from 7.5 to 8.4. Typical composition of seawater is sodium chloride (2.8%), magnesium chloride (0.3%), calcium chloride (0.1%), magnesium sulfate (0.2%), calcium sulfate (0.1%) and some dissolved carbon dioxide.

In terms of chemical attack, the damage from sulfates is not significant because in seawater, the deleterious expansion resulting from ettringite formation does not occur. The ettringite as well as gypsum are soluble in the presence of chlorides and can be leached out by seawater.

Frost damage, abrasion due to wave actions, salt crystallization, and biological attack are other factors that may lead to the deterioration of concrete. However, the main durability concern for marine structures is the corrosion of the reinforcement resulting from chloride ingress. Of particular interest is the splash and tidal zones.

To be durable under seawater exposure conditions, concrete must have an adequate cover and low permeation properties with the appropriate choice of cementitious materials. Seawater should never be used as mixing water for the production of reinforced or pre-stressed concrete structures[16].

3.3 TYPES OF DEFECTS IN EXISTING CONCRETE STRUCTURES

Various defects or signs of damage can be noticed in an existing structure due to a cause or a combination of causes. These defects can be minor with no structural influence in their initial stages, but if neglected they may progress to more severe stages that may cause structural deficiencies or failure. Also some of the defects may be signs of severe problems that if not repaired other severe problems may be faced. The following is a brief description of some common defects that may occur in concrete structures:

3.3.1 Crazing

Crazing, a network pattern of fine cracks that do not penetrate much below the surface, is caused by minor surface shrinkage. Crazing cracks are very fine and barely visible except when the concrete is drying after the surface has been wet. The cracks encompass small concrete areas less than 50mm in dimension, forming a chicken-wire pattern. The term "map cracking" in Fig. 3.10 is often used to refer to cracks that are similar to crazing cracks but more visible and surrounding larger areas of concrete. Crazing is not structurally serious and does not ordinarily indicate the start of future deterioration.

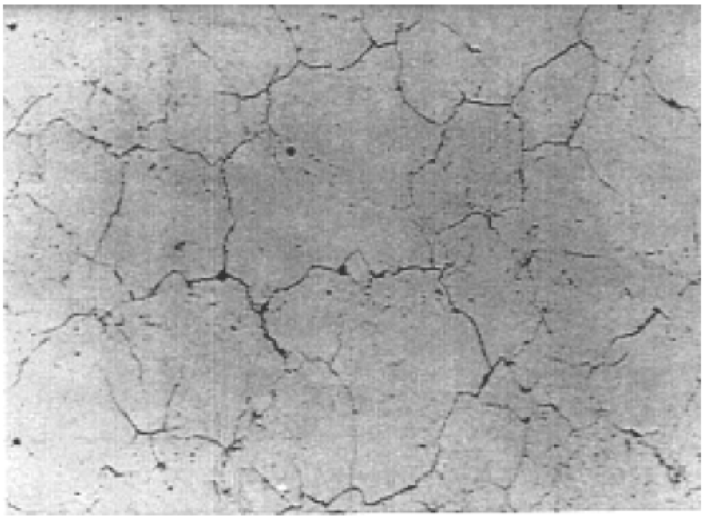


Fig. 3.10: Craze Cracks (Map Cracking).
(ACI 201.1R-92)

To prevent crazing, relevant curing procedures should begin early, within minutes after final finishing when weather conditions warrant. Curing with water when used stops rapid drying and lowers the surface temperature[15].

3.3.2 Curling

Curling is the distortion (rising up) of a slab's corners and edges due to differences in moisture content or temperature between the top and bottom of a slab. The top dries out or cools and shrinks more than the wetter or warmer bottom. If the curled section of a slab is loaded beyond the flexural strength of the concrete, cracks may develop to relieve the stress. The degree of curling is often significantly reduced with time as the slab dries and achieves a more uniform moisture content and temperature.

To repair curling, grinding may restore serviceability then Portland cement grout can be injected to fill voids and restore bearing in uplifted portions of a slab. After the grout hardens, the surface can be ground down to its original plane with power grinding equipment[15].

3.3.3 Dusting

Dusting as shown in Fig. 3.11 is the development of a fine, powdery material that easily rubs off the surface of hardened concrete. It can occur either indoors or outdoors, but is more likely to be a problem when it occurs indoors.

Fig. 3.11: Dusting of Concrete Surface.
(http://www.prairie.com)

Dusting is the result of a thin, weak layer, called laitance, composed of water, cement, and fine particles usually appears as a result of construction faults or concrete weakness. Floating and troweling concrete with bleed water on it mixes the excess water back into the surface, further weakening the concrete's strength and wear resistance and giving rise to dusting. Dusting may also be caused by water applied during finishing, exposure to rainfall during finishing, spreading dry cement over the surface to accelerate finishing, a low cement content, too wet a mix, and lack of proper curing (especially allowing rapid drying of the surface) [16].

3.3.4 Efflorescence

Efflorescence can be considered a type of discoloration. It is a deposit, usually white in color that occasionally develops on the surface of concrete, often just after a structure is completed. Efflorescence is usually harmless. In rare cases, excessive efflorescence deposits can occur within the surface pores of the material, causing expansion that may disrupt the surface.

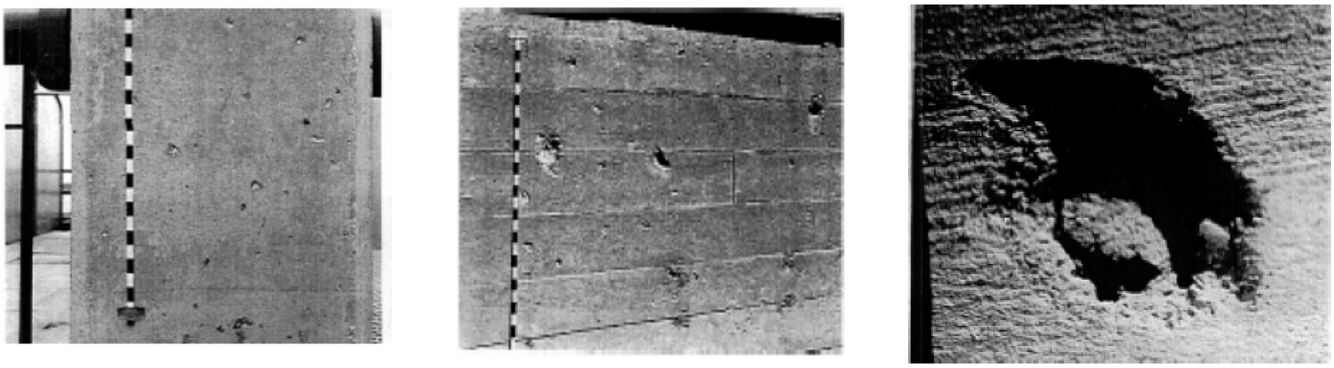
Efflorescence is caused by a combination of circumstances: soluble salts in the material, moisture to dissolve these salts, and evaporation or hydrostatic pressure that moves the solution toward the surface. Water in moist, hardened concrete dissolves soluble salts. This salt-water solution migrates to the surface by evaporation or by hydraulic pressure where the water evaporates, leaving a salt deposit at the surface. Efflorescence is particularly affected by temperature, humidity, and wind. In summer, moisture evaporates so quickly that comparatively small amounts of salt are brought to the surface. Usually efflorescence is more common in the winter when a slower rate of evaporation allows migration of salts to the surface. If any of the conditions that cause efflorescence water, evaporation, or salts are not present, efflorescence will not occur[16].

3.3.5 Popouts

A popout is a conical fragment that breaks out of the surface of the concrete leaving a hole that may vary in size generally from 5mm to 50mm, but may be up to as much as

300mm in diameter. They are divided into three types: Small, medium, and large as shown in Fig. 3.12 a, b, and c respectively.

Small Popouts are those leaving holes up to 10mm in diameter. Medium Popouts leave holes between 10mm and 50mm in diameter, and large popouts are those leaving holes greater than 50mm in diameter.



a- Small Popout b- Medium Popout c- Large Popout

Fig. 3.12: Popouts

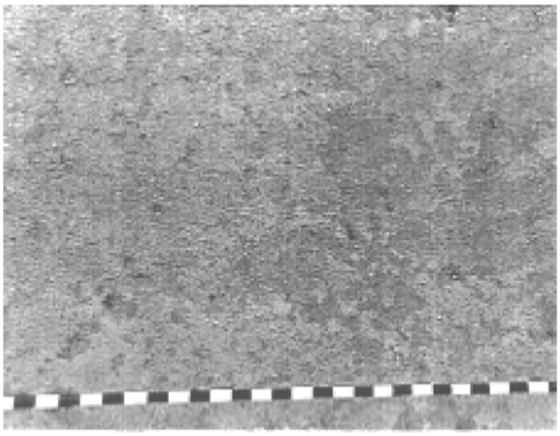
(ACI 201.1R-92)

The cause of a popout is usually a piece of porous rock having a high rate of absorption and relatively low specific gravity. As the offending aggregate absorbs moisture or freezing occurs under moist conditions, its swelling creates internal pressures sufficient to rupture the concrete surface. Most popouts appear within the first year after placement.

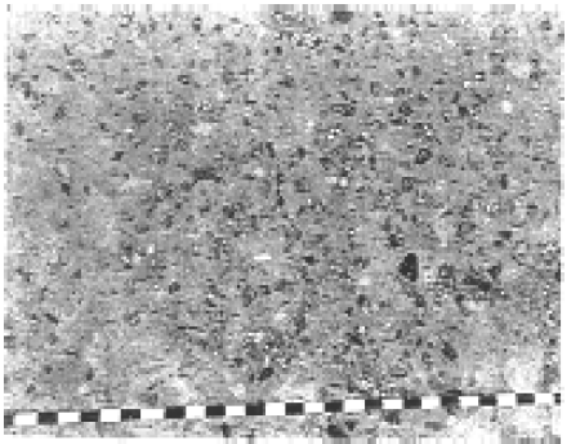
Popouts are considered a cosmetic detraction and generally do not affect the service life of the concrete[12].

3.3.6 Scaling

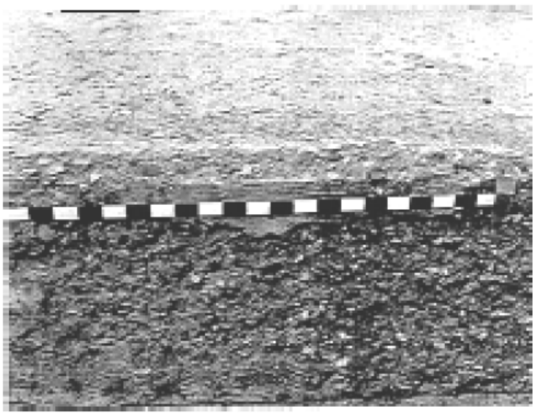
Scaling is a local flaking or peeling away of the near-surface portion of hardened concrete or mortar. It may be light scaling (loss of surface mortar without exposure of coarse aggregate), medium scaling (loss of surface mortar 5 to 10 mm in depth and exposure of coarse aggregate), severe scaling (loss of surface mortar 5 to 10 mm in depth with some loss of mortar surrounding aggregate particles 10 to 20 mm in depth), and very severe scaling (loss of coarse aggregate particles as well as mortar, generally to a depth greater than 20 mm). Fig. 3.13 illustrates these types of scaling[17].



Light Scaling



Medium Scaling



Severe Scaling

Very Severe Scaling

Fig. 3.13: Types of Scaling. (ACI 201.1R-92)

3.3.7 Spalling

Spalling is a deeper surface defect than scaling, often appearing as circular or oval depressions on surfaces or as elongated cavities along joints. Spalls may be 25mm or more in depth and 150 mm or more in diameter, although smaller spalls also occur. Spalls are described as small or large. Small spalls as shown in Fig. 3.14 (a) are roughly circular depressions not greater than 20mm in depth nor 50mm in any dimension while large spalls shown in Fig. 3.14 (b) may be roughly circular or oval or in some cases elongated, more than 20 mm in depth and 150 mm in greatest dimension

.

Spalls are caused by pressure or expansion within the concrete, bond failure in two-course construction, impact loads, fire, or weathering. Improperly constructed joints and corroded reinforcing steel are two common causes of spalls[17] [18].

(a) Small Spall

(b) Large Spall

Fig. 3.14: Types of Spalling (ACI 201.1R-92)

CHAPTER 4

LEGAL ASPECTS FOR REINFORCED CONCRETE STRUCTURES

4.1 INTRODUCTION

Urban growth coupled with rapid construction's projects emerged in response to the growing and steadily human needs is tied to scientific development that its footprint is evident in, for example, buildings 'construction and its massive scale as well as on time accomplishment of major development projects in terms of time and demands. However, shortfalls are common which emerge in response to the desire to satisfy welfare. As a result, problems arise in re-housing projects in particular because human safety in these projects is directly affected. This is because buildings in general represent stability in human lives due to being the starting point for human's everyday activities. And here lies the importance of buildings' regulations and constructions' laws in modern time [19].

Such rules fulfill their function through the lens of strict check out over the way construction projects are implemented which follows descriptions of safety's construction. On the other, strict bases that outline responsibility have been advocated and are strongly recommended in an attempt to encourage those on construction sites to follow not only appropriate implementation in accord to construction plans but also compensating those of key concern. Not only have rules been adopted but also it should be noted that construction stages include a number of aspects due to a complex network represented in human and cost factors. The design aspect is a central theme which is led by the engineer but largely implemented by the contractors under the supervision of the consultant engineers. As such, factors led to the final construction stage are intertwined to the extent that it is difficult to figure out responsibilities and who is responsible for the damage caused[19] [20].

To take the issue further in this chapter, it deems useful to explain these responsibilities at the construction stages in what follow. Of particular note is to shed light on the responsibility at the implementation stage while noting the several aspects of this responsibility associated with forensic causes.

4.2 THE FORMS OF LAWFUL RESPONSIBILITIES

Generally, failure on constructions' sites has several aspects which could be outlined in accord to the literature in four themes that mainly confront[19], for example, the engineer, contractors or employees being found guilty as follow:

1. **Forensic responsibilities**

Here, the key theme is a failure in construction which occurs on purpose leading to court's investigation. A failure in this respect follows in a direct response to ignorance, careless or, in some cases, overlooking the rules;

2. **Civil responsibilities**

In this responsibility, the discussion is about compensating those affected by the material damage as a result of construction damages; for example cracks and concrete deterioration;

3. **Administrative responsibilities**

The engineer, a technician or an employee may be of concern facing organizational and administrative questioning from relevant administrative bodies and local organizations, for example mistakes found in administrative archiving;

4. **Association responsibilities**

It is about the association's right to look into the process of how this association might follow the construction's stages. For example, one issue is establishing a fresh engineering office without license.

Having illustrated the four key responsibilities, as sketched above, the roles of engineers and contractors seems to be at stake. Despite differences, Egyptian, Algerian and Palestinian laws in this respect discuss these rules in terms of five and three spheres, respectively, as described below.

4.3 EGYPTIAN LAW

4.3.1 Engineers' responsibilities

The sole role of engineers is broadly understood within three themes. The first has at its core accomplishing the design without a direct reference to this design's implementation; therefore, only damages occurred to the buildings as a result of the design lay within the engineers' responsibilities, including a review and accomplishing a proper design well adopted to universal standard. The second theme points to the design itself where the engineers have to follow rules that include, but not limited to, restrictions relevant to the land permitted for construction while noting the area deemed essential to separate buildings from adjacent ones. The last theme highlights the damages caused to the buildings by the contractors. In this regard, the engineers are responsible for such damages once they are formally requested to supervise the relevant construction on site while not ignoring the responsibility of the contractors[19] [21].

4.3.2 Contractors' responsibilities

The contractors are only responsible for the damage caused on site while implementation, excluding those remaining within the design. The Civil Law titled 'initial project', No. 890, explains further as follow[20]:

- The contractors have the right to cease the construction process once discovering design errors; and
- The contractors have to maintain the construction process in case there are amendments in the design plans.

In addition, the contractors have the right not to continue the construction process, if the owners direct attention to construct irreverent work that is in contrasts the standard plans.

4.3.3 Shared errors of the engineers and the contractors

The court considers the percentages of errors occurred by both the engineers and the contractors in an effort to decide either responsibility. Two cases are relevant. On the one hand, the damages caused during the construction, for example, as a result of irrelevant construction's materials the contractors take to a large extent the responsibility for the errors caused while the supervising engineer is responsible, too to a less degree. In contrast, the other case notes that once the errors lay within the design stage the supervising engineers take the sole responsibility[19].

4.3.4 Defects caused as a result of construction materials

The materials used in accord to the bill of quantities are common issue for failures of the structures. Hence, a number of themes emerge which question whose responsibility for such failures and how to proceed with the process of compensation. Two pronged-aspects emerge in this respect which determine the level of compensation. The first aspect underlies the factor that notes the owners who provide the construction materials. The engineers and contractors remain responsible to a less degree considered when compensating. The second aspect notes that the engineers and contractors who are the providers of the construction materials. In this, both are fully responsible for substitute[19].

4.3.5 The responsibilities of errors caused by employees, technicians or sub-contractors

The errors caused by technicians also give the right for compensation. However, the responsibility for these errors refers back to the direct manager. The Egyptian law, No. 661, sheds light on the responsibility of sub-contractors by discussing two points. The first states that the main contractor has the right to authorize all or part of the construction work to the sub-contractor unless the contract does not state otherwise. The second point highlights that the main contractor is fully responsible for the construction errors caused by the sub-contractor. In addition, the former has the right legally review the latter in accord to the signed contract[19].

4.4 ALGERIAN LAW

Errors, defects and the causes are three aspects that lay the template for civilian responsibility in accord to article 124 included in Algerian Civil Law as follow: ‘Compensation deems essential once errors are approved which are apparent in defects caused to others'. The Law accordingly specifies in more detail how this might happen illustrating the errors caused by the engineers, both in the design and site supervision, followed by describing these caused by the contractors[22].

4.4.1 Errors in the design aligned to the engineers

The study and examination of errors is key to determine the engineers' failure to response, however, it should conducted within the time frame of design stage, followed by accentuating the most important features of errors occurred in this design. In so doing, two spheres are relevant. The first points to the activities processed by the engineers which deems essential to accomplish the design stage. The second highlights the characteristic that mark the errors occurred[22].

4.4.1.1 Activities included towards accomplishing the design

These include the responsibility to prepare the design and shop drawings, in addition to accomplishing relevant plans, or bill of quantities. To complete the design, the engineers have to process several activities inherited in mainly giving a legal and professional advices to the owners. In particular, the advices range from technical; soil, foundations, concrete or calculation, economical; the costs necessary to accomplish a proper construction, and finally legally that includes the extent to which the construction follows the legal aspects[22].

4.4.1.2 The characteristics embedded in the design stage

Legal implementation helps concluding the key features that mark the errors. Accordingly, the latter are categorized in terms of technical, economical and legal. The former include those designs that object the purpose originally set. For instance, designing for offices instead of commercial buildings. Also, accessibility and ensuring safety of all users, for example sound isolation and air circulation. Errors relevant to the foundation are also included in the advises which range from height of the construction, water level and wind circulation. Lastly, structural errors count which include advises related to columns, slabs and the structural system adopted.

The economical category are embedded in estimating the costs and selecting the economically relevant construction materials. The third category points to how the constructions follow legal and lawful aspects, thereby shedding light on the extent to which intended design might object buildings' law[22].

4.4.2 Engineers' and contractors' errors relevant to site supervision

Relevant to the engineers are errors that are classified into two major categories. The first underlies his/her responsibility to successfully conduct site supervisions, including construction management and monitoring its process. The former includes, for example, accomplishing the supervision in accord to time schedule, follow the implementation of the shop drawings and the extent to which the contractors hold into designed drawings. Monitoring is key because it helps accomplishing the construction as proposed, however, avoiding any unexpected any defect[22].

The second category points to the features that mark site supervision. These include gaining official permit to proceed with the construction, ignoring the revision of the drawings – here, it is forbidden for the site supervisors to proceed with construction errors accentuated when implementing, leaving aside to make certain that the construction materials satisfy the technical and universal standard[22].

In terms of the contractors' errors, there are two scenarios of importance. On the one hand, the role of the contractors is in question. Here, the contractors are aligned to the process of accomplishing the construction, paying sufficient attention while on site and being careful with the choice of materials in accord to the shop drawings. Responsibilities included in this role are accomplishing the construction on time and also avoiding any deviation to what is stated in the contracts[22].

On the other, the contractors are strongly advised to consult with the owners on matters related to the engineers' supervision and also to matters where the contractors may not be able hold into technical implementation in accord to the drawings[22].

4.5 PALESTINIAN CIVIL LAW

This law is key in terms of organising civil transactions occurred. Therefore, it is not surprising to suggest that the civil law is one of the main legislation to the extent that the law system has no effect[23].

4.5.1 Contractors' commitments[24]:

Article(739)

1- The contactor is allowed to pledge that he/she is going to achieve the work once the employer would supply the materials.

2-The contractor is also allowed to do both, working and facilitating the materials.

Article (740)

In case that the contactor is offered to provide all materials or some items, the former must not only hold into the conditions signed in the contract but also guarantee it's quality.

Article(742)

The contractor is committed to facilitate any additional machines and/or equipment deemed essential to achieve the project, except where disagreements that violate the law exist.

Article (743)

The contractor must achieve the work in due course in accord to the terms and norms stated in the contract.

While maintaining work in progress, employers may have the right to notify the contactors once it is approved that the latter violate the contract's terms. The former is entitled in this case to define suitable deadline to rearrange the correct order. Note that when the deadline passes without making any amendments, as reported in evidence of the violations , employers have then the right to dismiss the contractors, thereby repairing and accomplishing the work in progress on the expenses of previous contractors.

Employers have also the right to cancel the contract without a notice for determination once the repair stage is ineffective. Examples for cancelling the contract include the contractors' violation of the contract's terms, delaying the work and behaving in a way that reveals the contractors' intentions of less commitment to assigned responsibilities.

Article (744)

Both the engineer and the contractor follow what happens within a period of 10 years, including cases of total or partial destruction, even if the damage is as a result of a defect anchored in the land itself, unless the contractors meant to these installations to remain for less than a 10- year period.

Article (745)

If the engineer's mission is restricted to the design only excluding the supervision, the former is only responsible for the design defects. In contrast, if the contractor works under the supervision of the engineer who has conceptualised the designs, the contractor is only responsible for the defects occurred during the construction.

Article (746)

Any circumstances, that lead to exempt the engineer or the contractor from circumscribing guarantee or limit, are considered void and null.

Article(756)

The contractor is allowed to appoint a sup-contractor to execute the whole or part of the work, unless there is a statement in the contract which refutes this, or, if the nature of the project at grass roots requires the contractor to do the work himself. In this case the contractor is fully responsible for the sup-contractor before the employer.

4.5.2 The Palestinian labour legislation for the year 2000

In the case of having the work injuries, employers must do the following[23]:

1- To provide firstly aid services to the injured employees, and to take him to the nearest hospital.

2-To inform the police immediately, if the injury has led to the death of the worker or caused him severe physical harm, and to put the injured worker in to rest.

3- To send a written notification to the ministry and to the insurance company about every injury in a maximum period of 48 hours. And the injured worker is to be handed a copy of this notification.

4- To provide medical treatment to the injured worker until he recovers.

The injured worker has no right of compensation if it is approved that the injury resulted from:

1- Intended act by the injured.

2-Being under the effect of alcohol or drugs.

4.6 CONSTRUCTION CONTRACTS

It is clear that having a standard form of construction contract will make this standard form applicable everywhere, regardless of the location of the site. In the case of standard form, generally the intention at least is to establish a fair balance between the rights and obligations of the employer and the contractor. For example, as far as the FIDIC contracts are concerned they have traditionally been based on the principle of balanced risk sharing and, as such, have been widely accepted on the employer's and the contractor's side as a reasonable compromise[25].

A construction contract sets forth the intentions and procedures to be employed in any building effort. Ideally, it should be an easily understandable, mutually agreed-upon document that provides the answer to every project contingency. More realistically, these intentions and procedures often represent the owner's interests to which the business-hungry contractor agrees, with the hope that enough ambiguity resides in the document to permit multiple interpretations. The purpose of a contract is to set out the rights, responsibilities, and liabilities, of the parties. Meanwhile, the purpose of a contract can be described as a means to allocate risk between parties[25].

4.6.1 Construction contracts types

Contracts between the owner and the contractor are frequently divided into several categories. Each of these categories has several variations, usually determined by the type of fee the contractor is to be paid. These categories are[25]:

1. Lump sum contract;
2. Unit price contract;
3. Cost plus contract;
4. Design build contract;
5. Management-oriented contract;
6. Two stage selective tendering;
7. Negotiated contracting;
8. Continuity contracting;
9. Serial contract;
10. Turnkey contract

CHAPTER 5

ESTABLISHING A FORENSIC FRAMEWORK

5.1 INTRODUCTION

This chapter presents a framework enables conducting forensic investigation for buildings in the Gaza Strip. This framework seeks to implement the best forensic practices within engineering investigation relevant to all types of failure occurred in reinforced concrete structures. The effective forensic framework should satisfy the following features:

1- Simplicity and straightforwardness;
2- Touch upon the main causes of failure occurred in the Gaza Strip;
3- Relevance to all causes of failure in reinforced concrete structure; and
4- Marked by a small forensic team whose members stem from various institutions, in addition to being equipped with multi-disciplinary technical backgrounds.

The framework requires well-experienced and highly qualified forensic engineers in an effort to assess conditions of the structure, identify the causes of damage and determine acts that lay the template for the failure, thereby enabling the following objectives:

1- Asses the conditions of the structure followed by identifying the failures;
2- Focus on the causes of damage; and
3- Outline major and minor responsibilities of the failure.

5.2 PHILOSOPHY OF THE PROPOSED FRAMEWORK

The framework is processed into five stages, including the preliminary one, evidence collection, analysis and failure hypothesis, the conclusion stage, and, finally the responsibility stage as shown in figure 5.1. The narrative is discussed in this chapter in terms of content related to each stage followed by shedding light on each philosophy.

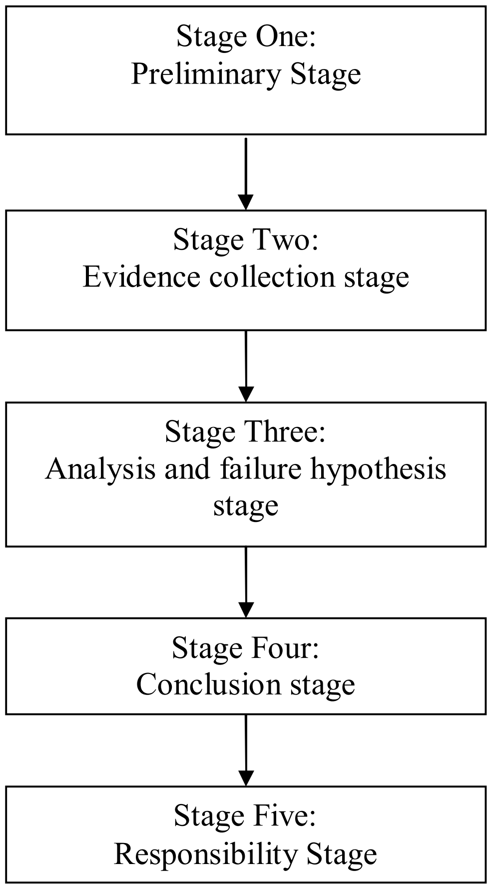


Fig. 5.1: Stages of the proposed framework

The preliminary stage is primarily concerned with not only addressing how to investigate the failure but also seeking necessary information related to buildings' structure which is enriched through the lens of a documentary analysis. Its philosophy revolves around how to organise the planning and setting included in data collection and reviewing documents as presented in Figure 5.2

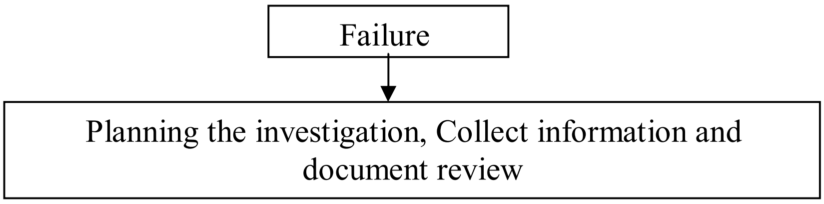


Fig. 5.2: Preliminary stage

The second stage has at its heart collection of evidences. In doing so, this stage involves site visits. Accordingly, the investigators are strongly advised to visit the site of concern, as early as possible, and in particular upon the failure being occurred in an attempt to eliminate any disturbance to the evidence. In turn, the site visit involves three components as shown in Figure 5.3 that neatly weave together the former's philosophy; namely visual inspection, eyewitness' information and lastly sample collection.

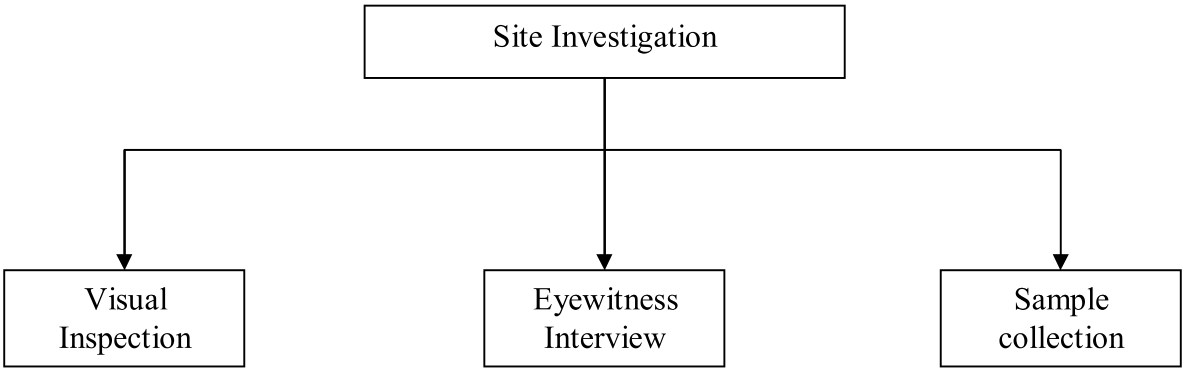


Fig. 5.3: Collecting evidence stage

The philosophy beyond the site visit remains effective due to its visual inspection, possible eyewitness' information and to easing the process tied to collection of the samples. Through the lens of photographic evidence, adopted as a method for the visual inspection, investigators are able observe the failure scene, thereby providing the main evidence that may report about how the failure occur. On the other, investigators while communicating to eyewitnesses on site seek to understand the actual modes and sequences of failure because eyewitnesses [often] provide valuable evidence to investigators. For example, eyewitness may report about causes that may lead to the failure as a result of casting without the engineer's check out. Differently but related, collecting the samples relevant to the failure is also a central theme step because it may reveal important evidence. The data collectively obtained at the site visit may shed light on the initial failure hypothesis to be examined at the third stage.

The third stage, or 'analysis and failure hypothesis', goes on to approve the data obtained previously. It comprises three approaches: carrying out testing methods, a critical review of relevant documents and , lastly, conducting depth interviews as shown in Figure 5.4. The philosophy of this stage is inherited in theses approaches. The testing methods are categorised as field and laboratory assessments, involving a series of non-destructive and destructive which will be carried out on site. The key purpose is to check the actual mechanism of concrete structure. Laboratory, on the other, involves specific tests that are commonly destructive in an attempt to examine capacity and mechanism of certain components of concrete structure. It may also involve chemical analysis, loading tests and other associated testing.

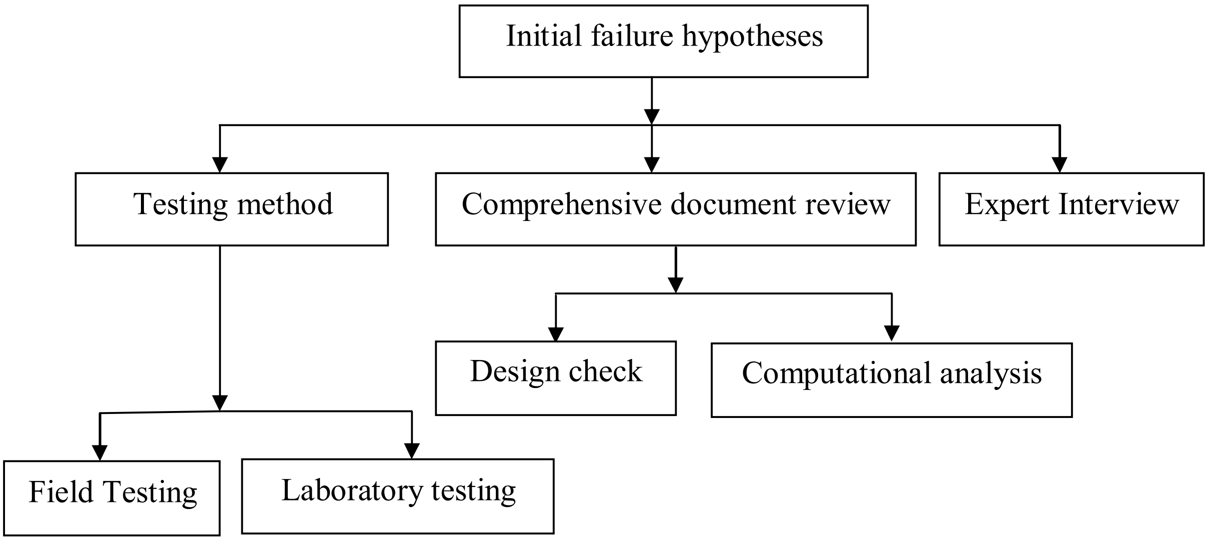


Fig. 5.4: Analysis and failure hypotheses stage

Notably, a review of documents involves ‘design check’ and ‘computational analysis’. The former includes the review of relevant documents related to the failure. By reviewing the documents, the investigators will be more familiar with the case and any discrepancies that will be detected. In so doing, computational analysis is a recommended using relevant software packages to analyse the concrete structure. A supplementary approach is therefore adopted in an effort to prove the 'failure hypothesis', for example using semi-structured interviews. In addition, an expert's expertise may also help prove the 'failure hypothesis', hence offering valuable explanations to the investigators towards understanding the cause of the failure. Upon completion of all analysis work could be undertaken to test the 'failure hypothesis'.

The next is the conclusion stage in which specific interpretations follow, namely from the findings derived from the evidence obtained which in turn lay the template for the causes of failure as shown in figure 5.5.

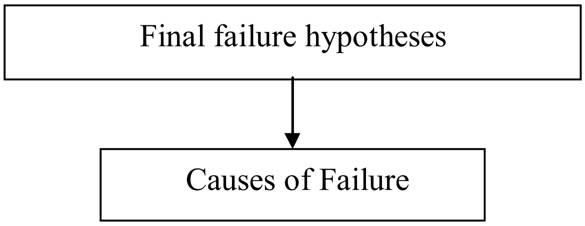


Fig. 5.5: Conclusion stage

The final is the responsibilities stage which determine the major and minor responsibilities related to contractor , engineers and owner according to the Egyptian law as shown in Figure 5.6. to achieve the final technical report.

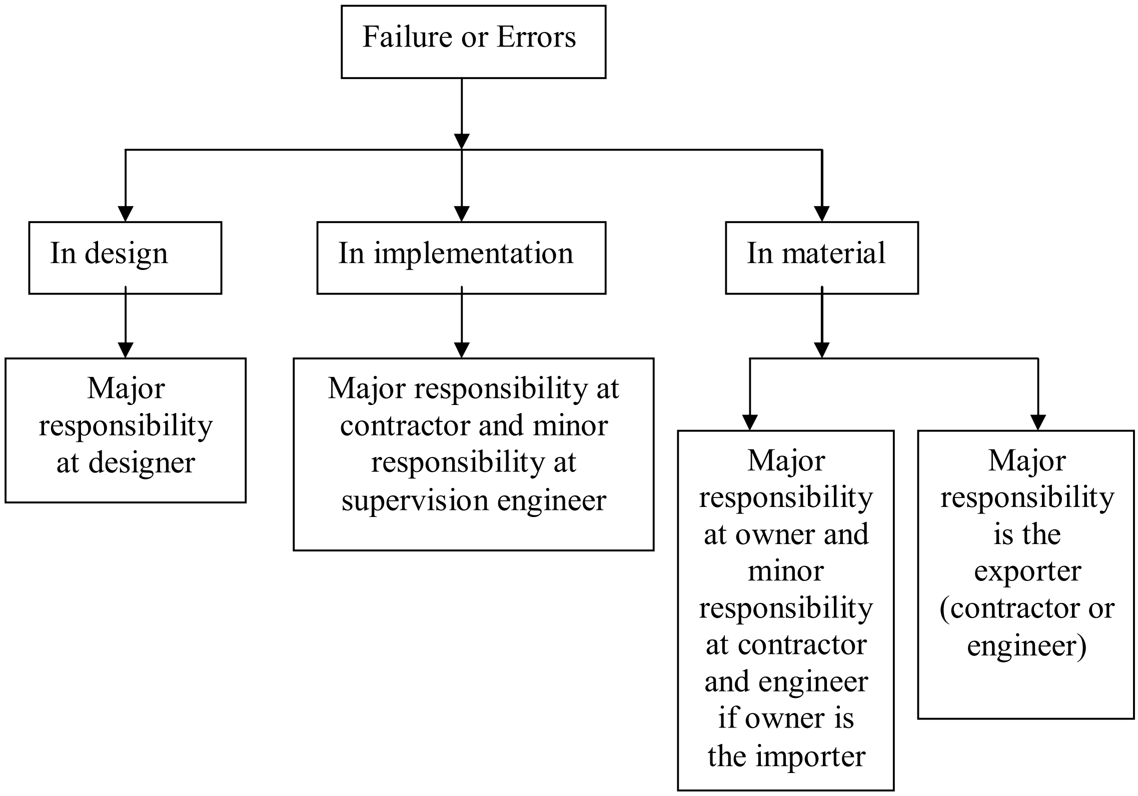


Fig. 5.6: Responsibilities stage[19].

The main five stages are collecting to consist the proposed forensic framework as shown in Figure 5.7

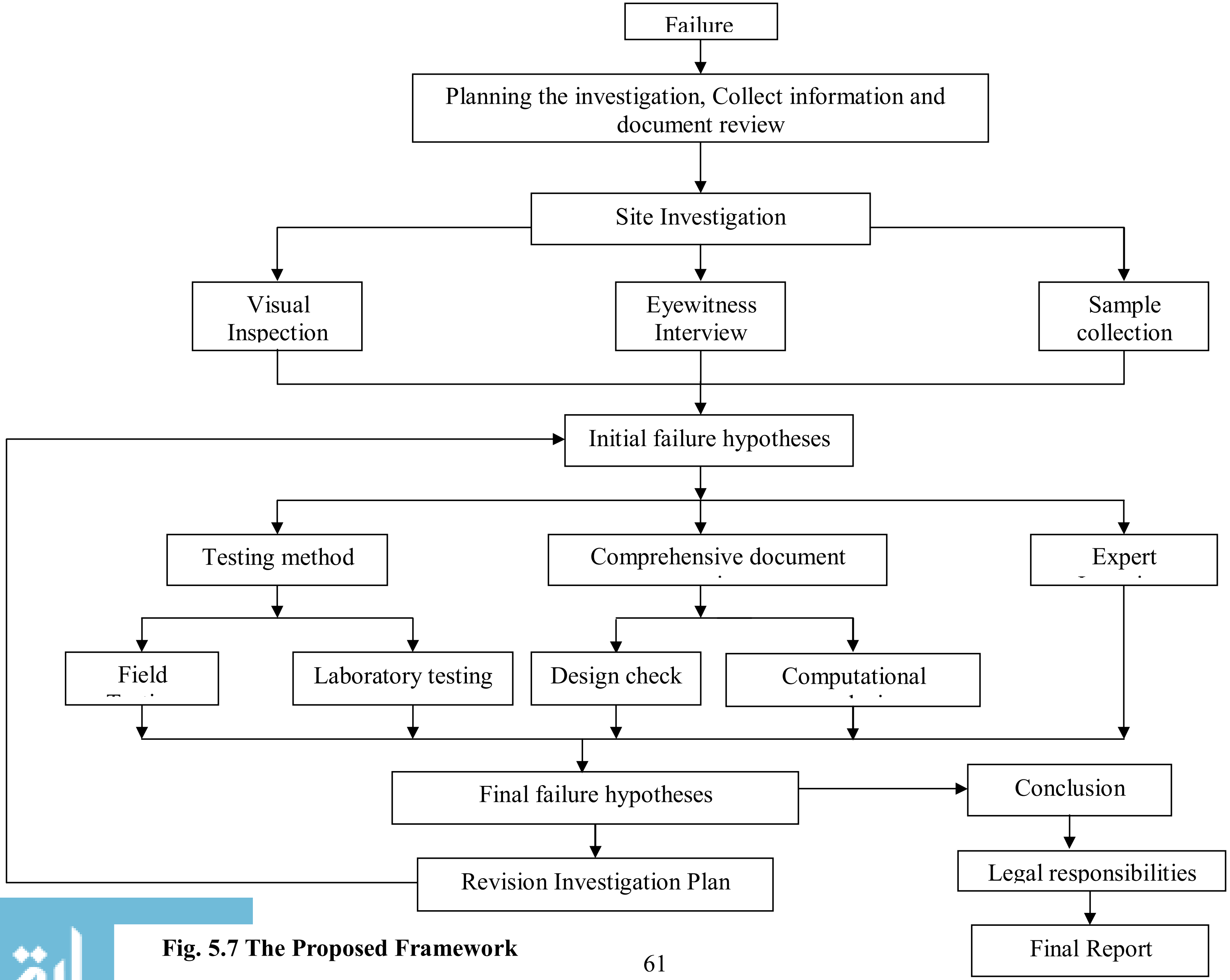


Fig. 5.7 The Proposed Framework

5.3 DETAILS OF THE PROPOSED FORENSIC FRAMEWORK ELEMENTS

There are few guidelines that may help structure the elements included in the proposed forensic framework, as described below.

5.3.1 Visual Inspection

Visual inspection seeks to evaluate the scope and nature of the failure at grassroots, thereby assisting the qualified forensic engineer in recognising perishable evidence and its potential value[26]. For those structures having sudden damage or collapse, it is advisable to perform the visual inspection immediately to avoid the evidence being lost or disturbed. Visual inspection will also lay the template for the basis of judgment associated with access' and safety's requirements, particularly when choosing both methods and locations of the test

Before starting the visual inspection on site, it deems essential to obtain and review both the construction drawings and other pertinent documents to be familiar with the environment conditions on site. In so doing, one method concerns taking photographs of the observed damage, since this method provides valuable photographic evidence to the investigators. It employs the service of a professional photographer who has the proper equipment for long-range and close-up photographs of the site. Sequential numbering and marking the location of the photographs on a sketch of the site plan may also help refresh recollection of where the pictures have been taken. Upon accomplishing of the visual inspection, the investigators suggest how the observations may be interpreted. As a result, the observations may generally entail the followings as shown in Figure 5.8:

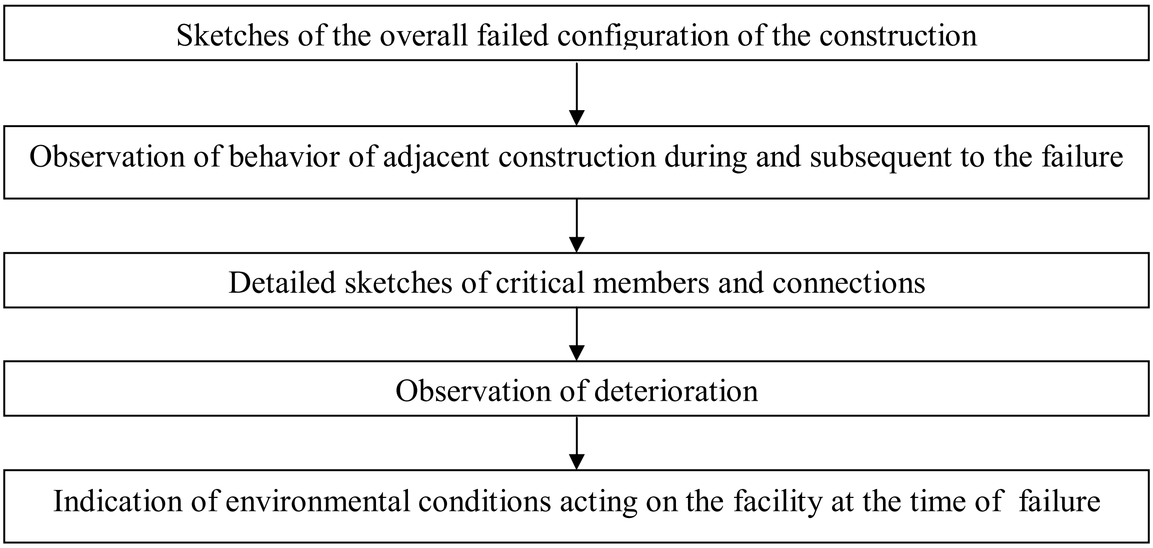


Fig. 5.8: Steps of visual inspection[26].

It should be noted that visual inspection is a subjective approach. This is because There is no generalised standard format that could be considered as a rule to record the data observed from the visual inspection. However, for the purpose necessary to record the information systematically, the consultant who is involved in the visual inspection will establish their own Form of recording the data as shown in Figure 5.9 and Table 5.1 presents relating symptoms to the cases of deterioration of concrete.

Table 5.1: symptoms to causes of deterioration of concrete[11].

Relating symptoms to causes of deterioration of concrete								
	Symptoms							
Causes	Construction Faults	Cracking	Disintegration	Movement	Erosion	Joint Failures	Seepage	Spalling
Accidental Loadings		x						x
Chemical Reactions		x	x				x	
Construction Errors	x	x				x	x	x
Corrosion		x						x
Design Errors		x				x	x	x
Erosion			x		x			
Freezing and Thawing		x	x					x
Settlement and Movement		x		x		x		x
Shrinkage	x	x		x				
Temperature Changes		x				x		x

Name of the inspector:	
Date:	
Time:	
Site Location:	

Feature	[*what kinds of problem / condition have been observed?*]
Description	[*Explain briefly the background of the problem, failure and effect of the failure to the surrounding area, what can be observed from the site.*]
Severity level	[*Low, Moderate or High*]
Cause	[*Initial failure hypotheses*]
Comment	[*Recommended from the inspector*]

Fig. 5.9: Standard form of the visual inspection

5.3.2 Eyewitness Interview

Eyewitness interview could outlined as a process to obtain information about failure of the concrete structures from key informants in order to assist in examining the failure hypothesis. This process could be accordingly either oral or written interview. In corroboration with the data obtained from the interviews, the latter lay the template for useful evidence, eliciting not only reliable data but also avoid leading questions. The information obtained is mainly used to guide the investigators.

Key informants provide the forensic engineer with the information necessary to explain the failure of the concrete structure. The former's account is valuable in formulating the hypotheses because their information help sharpening the investigations, thereby arriving at the most probable causes of the concrete failure.

5.3.2.1 Information Sought from the Eyewitness Interview

Although particular information is sought from the interviewees, the latter rely upon each case; nevertheless, certain questions as shown in Figure 5.10 are common to most failures as follow[4]:

a) If the collapse occurs at the time of construction, the forensic engineer will probably need to determine the status of the construction. Bearing in mind that the interviewee may have incomplete information about the construction, responses have to be compared with other accounts, for example physical evidence.

b) Sequence of the collapse. Identifying which element was the first to fail - or rather which area of the structure - could help a quick focus throughout the investigations. However, an individual's perception of the sequence largely depend on many factors, for example the speed of the collapse. It is rare that a single individual's perception of the sequence will be fully accurate or provide the complete picture. In all likelihood, it will be necessary to weave together the various accounts into a coherent sequence, thereby weighing the reliability of each account. In this respect, physical evidence is a central theme which help confirm or deny the many accounts.

c) Possible triggering events. Most collapses have a triggering event that needs to be identified to speed up the investigations. In some cases, the trigger is conspicuous, such as an errant barge striking a bridge pier; at other times it is subtle, for example the thermal cycle in a fatigue-critical member.

By conducting the interviews, valuable evidence is expected, largely due to the interviewees and passer eyewitnesses who may be able to provide useful information about the sequence of the collapse. Nevertheless, witnesses may not be familiar with the construction terminology; hence, they may not be able to express their observations in the interviewer's terms. This is because they have less association with the project.

Project eyewitnesses are those who have seen the collapse. Despite their familiarity with the construction eyewitnesses will generally be able to offer a more sophisticated account than account of a passer-by eyewitness.

Project personnel, for example project managers, design professionals and foremen, are associated with the project, however, they have not seen the collapse. These persons may have knowledge about the status of the concrete construction, the latter's activities that were under way, the design or construction of the structure, or, other useful background information.

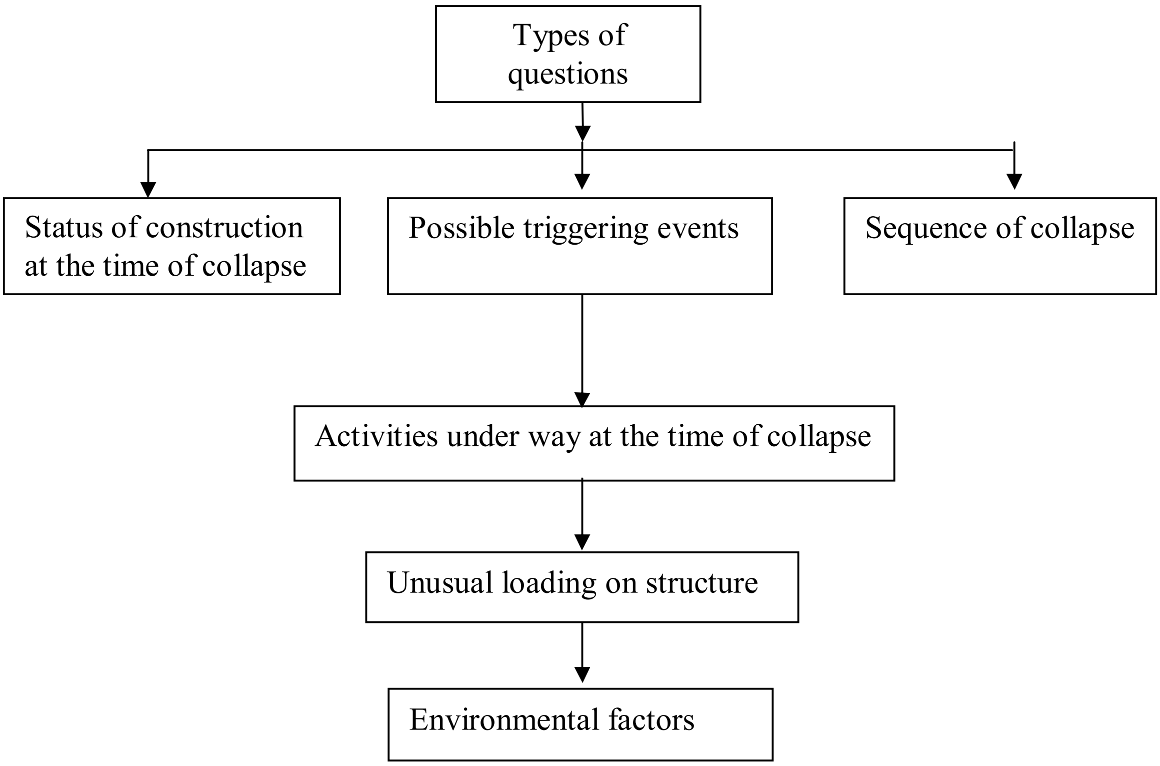


Fig. 5.10: Types of Questions in Eyewitness Interview

5.3.2.2 Form of the Eyewitness Interview

This form is marked by a typical interview questions, as shown in Figure5.11, that seek responses related to the eyewitness interview process, and figure 5.12, mention people who may be questioned.

Name of person:
Date:
Time:
Duration of interview:

1. What is your name? Who is your employer? What is your position?
2. What is your experience and education?
3. Where were you at the time of collapse?
4. What were you doing?
5. What was the first indication that something was wrong? Describe it.
6. What happened next?
7. What was the status of construction at the time of collapse?
8. What was the weather?
9. Will you let me know if you think of any thing else that may be helpful?

Fig. 5.11: Typical Interview Questions and Information

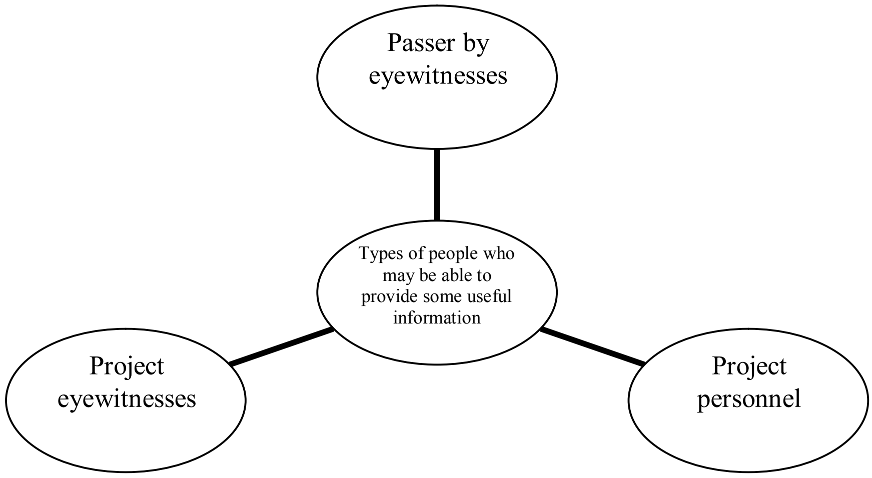


Fig. 5.12: People who may be questioned

5.3.3 Sample Collection

In structural forensic investigation, sample collection is a very important investigation approach to collect the evidence. The samples which are collected can be in the group of failed components or the group of non-failed components. The evidence obtained from both group of components play a crucial role in determining the most likely cause of the failure and contributing factors. Some of the evidence is durable and will remain reasonably intact over a period of time. For this type of evidence, it is named as non-perishable evidence. However some of the evidence is of a perishable nature and it is necessary that these are quickly documented or collected to avoid any disturbance to the evidence.

The purpose of sample collection is to preserve the perishable and non-perishable evidence correctly without disturbing them. Failed components can provide valuable information about the failure since the failed items are suspected of being associated with the initiation or propagation of the failure, so by carrying out investigation or testing on the failed components, the cause of failure can be determined. However the non-failed components can be useful for several purposes as follows:

a) To be uses in a testing program. Care must be taken to ensure that the selected sample was not materially damaged in the collapse; especially when the results are to be used as a basis for estimating the strength of similar failed components.

b) To study their construction.

c) To study differences between them and compare with failed components.

d) To exemplify to audiences, particularly non-technical persons, what a typical non-failed component looks like or how it functions.

e) To conclusively show that a certain component did not fail.

Before removal of any sample, it should be labelled and detail of its position and condition recorded together with photographs. After removal, samples must be maintained by responsible persons under a chain of possession in order to enable easy identification in the future.

The limit laboratory testing costs and minimizes destruction of evidence; samples should be taken only to establish parameters significant to the investigation. Sample removal should be based on the recommended standard. The number and location of samples should be carefully planned and is influenced by a number of factors, such as variation from sample to sample, degree of reliability required in result, whether there are any explainable trends in test results. Most often, the selection is based on more practical considerations, such as the availability of good samples and on the judgement of the investigation.

During sample collection, it is necessary to use a systematic labelling scheme in order to classify the sample types effectively. There are several types of the labelling system as shown in Figure 5.13 of which three of the most commonly used are the following:

a) Identity piece-mark system - If the identity of a piece is known, it can be labeled with an identity piece mark that is keyed to a drawing. If the original orientation of the element is known from its context in the debris, but may be readily apparent, it should be marked on the piece, for example, “north flange” or “bottom end”.

b) Serial piece-mark system - In some cases, the identity of a piece may not be known with certainty such a piece should be labeled in this cases with an arbitrary-but unique-piece mark. This piece mark is arbitrary in the sense that it conveys no information about the identity of the piece; it serves solely as a label to distinguish this piece from other pieces. This assigned piece mark must be unique over the entire project.

If multiple persons are simultaneously assigning the piece marks, ascribing the person initials on the piece mark will help in ensuring uniqueness. Obviously any information that may be useful in identifying the piece at a future date, such as where it was found, should be recorded either directly on the piece or in field notes.

c) Match-mark system - Match marking of mating segments can greatly facilitate later reconstruction. Match marking consists of marking both sides of mating segments with an identical label. If necessary, a match point can be indicated on the mating ends so that they can be reconstructed with the proper relative orientation. When used in conjunction with a piece-mark system, the match-mark pairs need only be unique to that piece. For example, “Match 1” may suffice if both segments are already marked with the same piece mark. If used as a stand-alone notation, each pair of match marks must be unique over the entire project, so that the marks will not be complication[4].

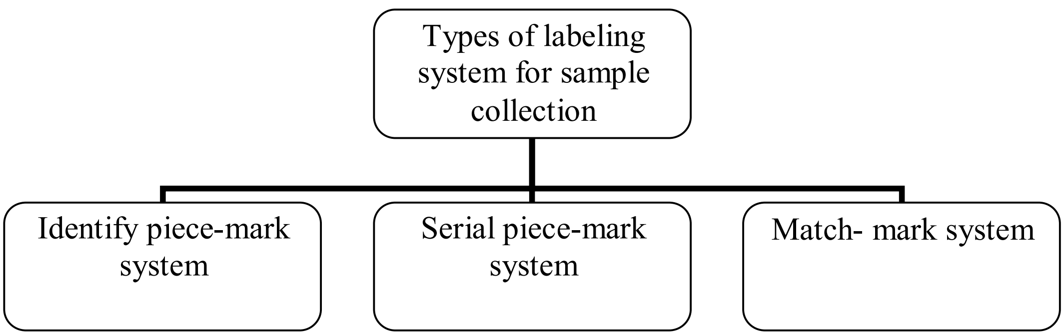


Fig. 5.13: Types of labeling system for sample collection

5.3.4 Field Testing

Field testing is a series of non-destructive and destructive in-situ testing in order to check the actual behaviour of the structure on site. As the name implies, nondestructive testing do not cause any damage or disruption to the site. However destructive testing are involved by removing limited sections of the building. By this way, the site had been disrupted during testing.

Field testing generally falls into two types, there are:

a) Load testing – It is useful when an undamaged portion of the structure exist and is representative of the failed section. They are particularly useful when the structure is severely deteriorated.

b) In- situ material testing – This type of test is carried out to determine the properties and strength of the material used on site.

The purpose of a series of in-situ testing is to check the actual behaviour of the structure on site. By carrying out the in-situ load test, the static, dynamic and fatigue behaviour under load of structural system or components is determined. However by the material testing, the estimating of the in-situ strength and properties of material can be determined easily without executing any laboratory testing.

The other purpose to carry out field testing is to collect and prove the evidence scientifically, in order to determine the cause of failure. Types of field testing are mentioned in Figure 5.14

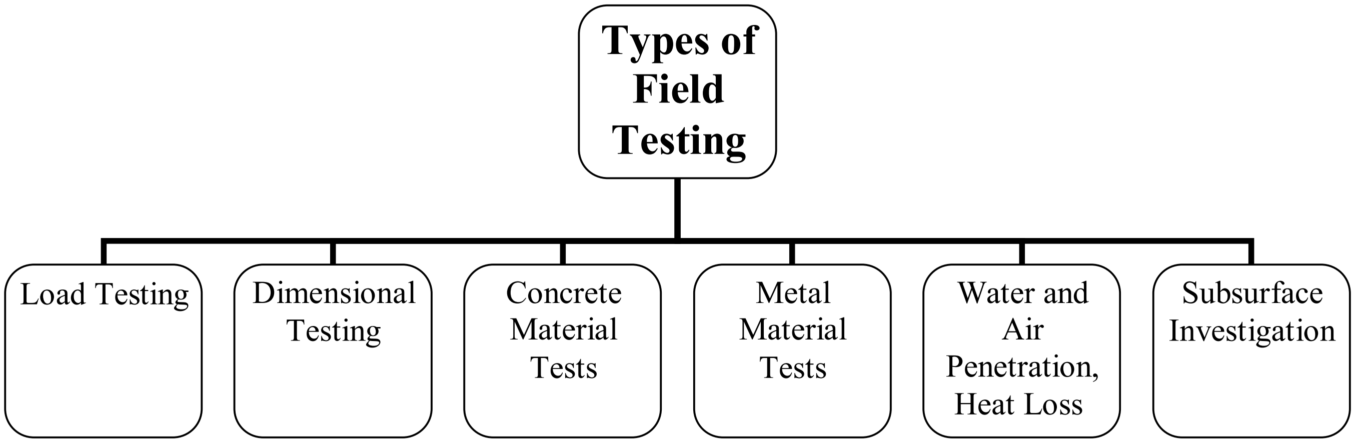


Fig. 5.14: Types of Field Testing[3].

5.3.5 Laboratory Testing

A series of laboratory testing are applied to the samples obtained from the failure site to check their characteristics and behaviour under certain condition. The testing sample can either be a sample obtained form site or a mock-up imitated in laboratory.

There are several types of laboratory testing in structural investigations as shown in Figure 5.15 such as components or mock-ups load tests, material testing on concrete, metal, masonry, wood, weld inspection, model tests, water and air penetration and scanning electron microscopic.

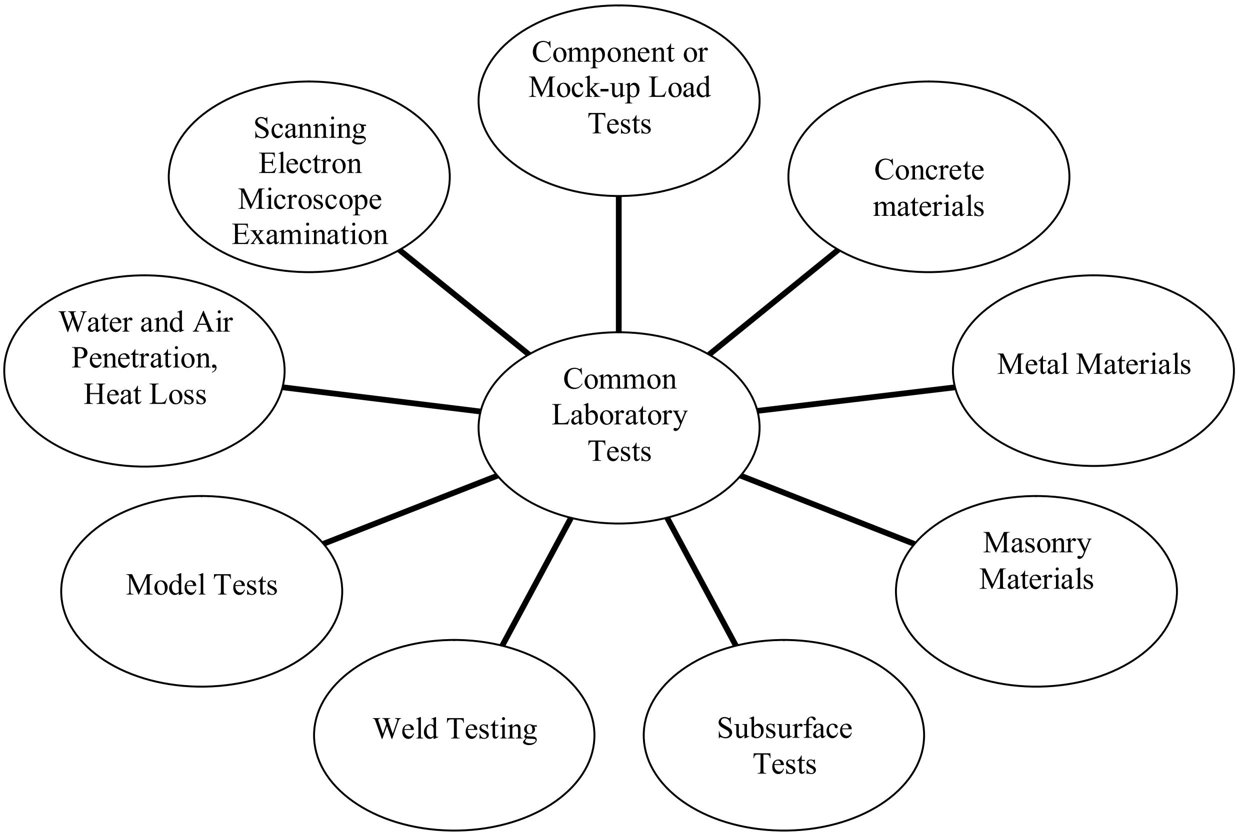


Fig. 5.15: Types of Laboratory Testing[3].

The main purpose of the laboratory testing is to check the behaviour and characteristic of the sample with the more detailed method compared with field testing by the assistance of the laboratory equipment. By using the laboratory equipment, the more complex and detailed experiment work can be carried out to the sample in order to find the cause of failure.

Beside that, by conducting the laboratory testing, a comparison between the result of the in-situ testing and the result of the laboratory testing can be carried out. If there are variations between the results, the investigators can carry out the detailed analysis for finding the cause of difference. By this way, investigators will understand more of the behaviour of the sample.

5.3.6 Design Check

Design Check and review is usually an ongoing process throughout the investigation. At the outset of the assignment, the investigators attempt to obtain pertinent documents regarding the overall design and construction of the facility to become generally familiar with the project.

The document may be readily obtained or will require perseverance. The types of documents fall into two categories, namely:

a) Project-specific documents – This type of documents are regarding the history of design, construction, modification, operation, and prior investigation of the facility in question.

b) Research documents – This type of documents are regarding the characteristic and performance of key systems or element of the facility.

Project documents especially the design drawings are essential to understand not only how the structure was built but also how it was maintained and modified over time. Without such documents the job is almost impossible for a complex project.

Project documents are also essential when the forensic engineer is called upon to opine on the procedural causes of the failure in that the documents provide insight into the actions of those responsible for the design, construction and operation of the structure.

Besides that, by carrying out the design check, it can determine the degree of conformance of the structural design to applicable standard.

The project documents are reviewed to assist in determining:

a)The operating condition of the structure such as strength, serviceability or process function.

b)The operating effects acting on the structure such as load and environmental conditions.

c)The allocation of responsibilities of various parties for the causes of structure.

The sources of the project documents are from:

1- Architects and engineers involved in original design, modification, or repair of structure.

2- Past and present owners or tenants.

3- General contractor, construction manager and subcontractors for original construction, modification, or repair of structure.

4- Developer of structure.

5- Construction mortgagee of structure.

6- Materials or systems suppliers for original construction, modification, or repair of structure.

7- Testing agency involved in original construction, modification, or repair of structure.

After the investigator have obtained the documents, detailed analysis, checking and comparison between the original design and actual construction method should be carried out in order to search the factors that contributed to the failure.

5.3.7 Computational Analysis

Computational analysis is an investigation approach by using either hand calculation or computer engineering software to analyse the structure. This is a theoretical analysis to check the performance of the structure under serviceability or ultimate condition.

The common purposes of performing structural and geotechnical analyses in investigations are to determine the causes of failure and to establish the degree of conformance of the structural and geotechnical design to applicable standards.

Structural analysis may attempt to determine stress, strain, strength, deflection, dynamic response (transient or harmonic), fatigue, fracture, or stability, however geotechnical analysis deal with strength, soil pressures, long-term and short-term settlements, and slope stability in order to determine limitation and capacity of the structure.

Computational analysis involves complex calculation to analyse the structure. There are two options that can be carried out to do the calculation:

1- Hand solution (often based on previously performed research).

2- Computer engineering software with the principle of finite-element or finite difference analysis.

For calculations to determine the causes of failure, analyses that include geometric and material nonlinear behaviors frequently are necessary. Computer codes for finite-element and finite-difference analysis, such as ANSYS, LUSAS and STAAD.Pro are readily available for these analyses. Secondary stresses from the effects of temperature, humidity, creep, shrinkage, foundation settlement, stresses induced during construction, and joint eccentricity also need to be considered. When the overall distribution of forces within the structure has been established, the next step is determining the resistance of a particular member, connection, or geotechnical element by using hand solution or computer engineering software.

It is necessary to avoid blind over reliance on complex computer method. Each finite-element analysis should be checked for satisfaction of overall equilibrium and should be scrutinized for qualitative response. Simple and approximate checks by hand solution to complex computer models should be made. Probabilistic reliability analyses that account for the variation in the parameters the engineer has estimate for strength and resistance are common in failure investigation.

5.3.8 Development of Failure Hypothesis

5.3.8.1 Initial Failure Hypothesis

Initial failure hypothesis is a preliminary estimation of failure scenarios and mechanisms of the structure. This hypothesis is developed at early stage in the investigation works, initial failure hypothesis is developed based on the preliminary evaluation of the finding evidence on site before any detail testing and analytical method have been carried out. The purpose of development of initial failure hypothesis is as a guide to the investigators.

5.3.8.2 Final Failure Hypothesis

Final failure hypothesis is a final and extract failure scenarios and mechanisms of the structure. The hypothesis had been scientifically confirmed with a series of testing and analytical method. This hypothesis also explains the actual cause of the failure to the structure.

In order to establish the cause of failure to certain case, the investigators must do two things:

1- Determine the mode and sequence of failure.

2- Establish that for the initiating location of failure and for each successive step in sequences of failure the demands on the structure (such as loads, environmental factors) exceeded its ultimate capacity (strength, stiffness or durability.)

CHAPTER 6

VALIDATION OF THE DEVELOPED FORENSIC FRAMEWORK

6.1 INTRODUCTION

This chapter aims at validating the developed forensic framework which was introduced in chapter 5. Here, validation is applied at two stages. The first concerns with testing the proposed framework using three case studies. A comparison follows which occurs between the proposed forensic framework and other relevant frameworks. Notably, the case studies have been selectively chosen because these are inherited in both varying types of structural forms and different causes that mobilise the failure. The first case study presents the collapse of *Alhuda* mosque slab while casting in 2010,in Rafah city. The second case study is the Collapse of *Hyatt Regency Walkway* existed in Kansa City, 1981. The collapse witnesses a damage of 40 – story tower which occurred upon four years of accomplishing the construction; particularly the incident occurred at the 2^{nd} and 4^{th} floors suspended corridors. As a result, 114 people died and over 200 others were injured. The third case study is of interest due to cracking problem occurred on the Flyover Bridge, in 2004, to be found in pier crossheads supporting the bridge. Certain consistent pattern followed being remarkably visible; their affect causes major concern. In what follows, the three case studies are discussed in elaborative way.

6.2 CASE STUDY 1: COLLAPSE OF ALHUDA MOSQUE SLAB

6.2.1 Background

The collapse of slab's mosque occurred while casting on February 5^{th} 2010. Briefly, the mosque is labeled *Al-huda* and exists in Rafah city, southern the Gaza Strip. In response, a committee has been formed which its members are engineers who belong to the Engineers Association in Rafah city. Upon accomplishing the investigation, the team of the committee has submitted its report in which it is explain how the collapse occurred. A key note in this report sheds light on how the slab was actually constructed, coupled with the conditions surrounded the collapse, for example the rainy weather at the time of casting. This note explains the main reason behind the collapse which primarily lies in not only insufficient vertical supporting legs but also points to the distance in-between which was indeed too long while casting .In addition, the committee has suggested few recommendations that might help obscure the collapse of the constructed elements.

However, the report remains at impasse. A number of reasons support this argument. One may argue that the former is not only insufficient but also lacking serious information. This is because there is not a particular framework adopted to explain how the recommendations are formed. Furthermore, the report does neither point to the position nor legal responsibility of the site supervisors being involved in the casting. Instead, all recommendations blame the contractor highlighting his/her failure. Neither does the report include any attached photos of the collapsed slab nor any sketches that might help support the recommendations being made.

6.2.2 A comparison between current framework and the case study Methodology

Table 6.1 shows below a comparison between the proposed framework and the methodology followed in the preparing of technical report in case study 1. The comparison is carried out based on six items.
The table shows that there are several missing elements in the technical report of the case study such as sample collection, field and laboratory testing, documents' review, experts' interviews and, including but not limited to, major and minor responsibilities. Other key elements include the lack of direct responsibility that causes the failure while noting the engineer's and contractor's responsibilities in particular, in addition to a serious lack of broad guidelines needed to fulfill the visual inspection. As a note, the report does not show the presence of an investigation team immediately after the failure occurred. This is because the incident occurred early morning on Friday whilst the team was at the site late in the evening at the same day. Also the lack is of documentary photos that enrich the reports; therefore, the report shows lack of serious concern such as evidence-based facts. In conclusion, the report does not include the necessary steps deemed essential to explain the causes of the collapse. To stem the report's lacks, the below steps are necessary.

Table 6.1: A comparison between current framework and methodology of case study

No.	Items	Proposed framework	Case study 1	Notes
1	Preliminary Stage	Planning and document review	√	
2	Evidence collection stage	Visual inspection	√	No specific guidelines
		Eyewitness Interview	√	
		Sample collection	X	
3	Analysis and failure hypothesis stage	Initial failure hypotheses	√	
		Testing method	X	
		Document review	X	
		Expert interview	X	
4	Conclusion stage	Final failure hypotheses	√	
5	Responsibilities stage	Contracts' and engineers' responsibilities	X	
6	Specific guidelines for investigation	Guidelines for visual inspection and site investigation	X	

6.2.3 Contents of Technical Reports

- **Introduction**

In this section, the objectives and scope of the investigation as well as whose being Responsible for the design and construction entities.

- **Description of the structure (or, project)**

The discussion sheds light on the general description tied to the structure and its location as well as its material and the document correlated with the structure.

- **Field investigation**

The theme at stake is the investigation team which highlights the preliminary steps deemed essential to carry out the investigation. Recording the observations also counts which ranges from the visual inspection to taking photos, thereby leading to preliminary failure hypotheses

- **Laboratory and Field Tests**

Laboratory and field test are of concern which point to material of the structure in an effort to figure out the capacity of structural elements, in addition to some chemical test results deemed essential to verify the hypothesis of failure

- **Field investigation and results of the calculations**

The results tied to both the tests and other supporting information, notably eyewitnesses interview and expert information, are discussed here.

- **Conclusions and final hypotheses**

The final hypotheses that explains the cause of failure in accord to the investigation team is a key theme in this section.

- **Legal responsibilities and Recommendation**

The major and minor responsibilities as well as the recommendations of the investigation team should be highlighted.

6.3 CASE STUDY 2: HYATT REGENCY WALKWAY COLLAPSE

6.3.1 Background

In July of 1980, the Hyatt Regency in Kansas City, Missouri opened to the public after four years of design and construction. A 40-story tower, an atrium, and a function block, housing all of the hotel's services, combined to form this impressive building. Three walkways suspended from the atrium's ceiling by six 32-mm-diameter tension rods each spanned the 37-m distance between the tower and the function block. The 2nd floor walkway, was suspended from the beams of the 4th floor walkways, while the 3rd and 4th floor walkways hung from the ceiling.

During construction, the atrium roof collapsed as a result of inadequate movement in the expansion joint and improper installation of a steel-to-steel concrete connection. Concerned about the building's structural integrity, the owner hired another engineering firm to investigate the collapse and check the roof design. The consulting structural engineering company also rechecked all of the connections and found nothing to cause alarm. Construction resumed and the hotel opened a little less than 2 years later.

On the evening of July 17, 1981, between 1500 and 2000 people inundated the atrium floor and the suspended walkways to see a local radio station's dance competition . At 7:05, a loud crack echoed throughout the building and connections supporting the ceiling rods that held up the 2nd and 4th floor walkways across the atrium failed, so caused the 4th floor walkway collapsed onto the 2nd floor walkway and then both walkways collapsed onto the crowded 1st floor atrium below that killing 114 people and injuring over 200 others, while the offset 3rd floor walkway remained intact. It was the worst structural failure in the history of the united states.

6.3.2 A comparison between the current Framework and the case study Methodology

As illustrated in Table 6.2, a comparison between the proposed framework and the methodology followed in case study methodology. The comparison is carried out based on six items also

Table 6.2: A comparison between case study 2 and the current framework

No.	Items	Proposed framework	Case study 2	Notes
1	Preliminary Stage	Planning and document review	√	
2	Evidence collection stage	Visual inspection	√	No specific guidelines
		Eyewitness Interview	√	
		Sample collection	√	
3	Analysis and failure hypothesis stage	Initial failure hypotheses	√	
		Testing method	√	
		Document review	√	
		Expert interview	√	
4	Conclusion stage	Final failure hypotheses	√	
5	Responsibilities stage	Contracts' and engineers' responsibilities	X	
6	Specific guidelines for investigation	Guidelines for visual inspection and site investigation	X	

Table 6.2 shows that most of items in the case study methodology are satisfied. However the methodology of the case study does not include the responsibilities stage to specify the major and minor response of failure causes, on the other hand, no specific guideline for the investigation explained in the methodology.

6.4 CASE STUDY 3: CRACKING PROBLEM ON FLYOVER BRIDGE

6.4.1 Background

This case study involves the investigation of crack in a flyover bridge which carries a dual 3-lane elevated carriageway on existing roads. The bridge cross- section comprises twin precast segmental concrete single-cell box girders. Extensive cracks were observed in 31 pier crossheads supporting the bridge which is located in a busy flyover interchange. Cracks in the affected crossheads were found to follow a certain consistent pattern and were visible to the passers-by and their presence had raised public concern. Repair work on the defective flyover had been temporarily halted to allow an independent investigation on the bridge structure to be carried out.

A forensic investigation has been carried out to determine the cause of the cracking and to check for any discrepancies in the construction of the structure. The forensic investigation into the cracking comprised of field investigation and related laboratory work, design checks and document study.

The field investigation involved visual inspection and crack mapping to verify earlier inspections, cover meter survey, rebound hammer tests, core-drilling for concrete strength sampling and related laboratory testing including core testing, ultrasonic pulse velocity measurement and chemical analysis. The test results indicated that the material used in the construction was in accordance with the specified material properties and strength.

The design check involved load assessment and structural analysis of the crosshead including code assessment, and finite element analysis as well as 2-D strut- and- tie analysis as a supplementary method. All the loading were verified and used in the design check.

6.4.2 A comparison between the current framework and case study Methodology

As illustrated in Table 6.3, a comparison between the current framework and the methodology followed in case study methodology. The comparison is carried out based on six items also

Table 6.3: A comparison between case study methodology and the current framework

No.	Items	Proposed framework	Case study 3	Notes
1	Preliminary Stage	Planning and document review	√	
2	Evidence collection stage	Visual inspection	√	No specific guidelines
		Eyewitness Interview	X	
		Sample collection	√	
3	Analysis and failure hypothesis stage	Initial failure hypotheses	√	
		Testing method	√	
		Document review	√	
		Expert interview	X	
4	Conclusion stage	Final failure hypotheses	√	
5	Responsibilities stage	Contracts' and engineers' responsibilities	X	
6	Specific guidelines for investigation	Guidelines for visual inspection and site investigation	X	

Table 6.3 shows that most of items in the case study methodology are satisfied. However the methodology of the case study does not include the responsibilities stage to specify the major and minor response of failure causes, on the other hand, no

specific guideline for the investigation explained in the methodology. In addition to the expert and eyewitness interview also missing.

In conclusion all mentioned case studies mostly satisfy the main items of the proposed framework. However the responsibilities stage are missing in all of them. In order to develop a full framework the legal aspects should be include in the framework

6.5 A COMPARISON BETWEEN THE PROPOSED FORENSIC FRAMEWORK AND OTHER FRAMEWORK

The comparison includes six items that explained in chapter 5 to compare the content of the proposed framework with other frameworks all over the words as illustrated in table 6.4

6.5.1 A comparison with Harry Poulos Framework

This framework describes a relatively simple framework for investigating the possible causes of foundation failures in a systematic manner. Attention is confined to foundation failures (ultimate failure conditions), although similar principles can be applied to cases involving excessive deformations of the foundation system (serviceability failures). The importance of developing alternative hypotheses and then testing them against the available information will be emphasised.

The below comparison shows that current framework agree very well with that of Poulos framework. However, Poulos framework does not include any legal aspects in his framework. this short come is overcoming the established forensic framework by adding items related to the legal aspects. Therefore the current framework is advanced over Poulos framework in relating the cases of failure with responsibilities.

Table 6.4: A comparison between the current framework and Harry Poulos Framework

No.	Items	Proposed framework	Case study 3	Notes
1	Preliminary Stage	Planning and document review	√	
2	Evidence collection stage	Visual inspection	√	True or False framework
		Eyewitness Interview	X	
		Sample collection	√	
3	Analysis and failure hypothesis stage	Initial failure hypotheses	√	
		Testing method	√	
		Document review	√	
		Expert interview	X	
4	Conclusion stage	Final failure hypotheses	√	
5	Responsibilities stage	Contracts' and engineers' responsibilities	X	
6	Specific guidelines for investigation	Guidelines for visual inspection and site investigation	X	

Fig. 6.1: photo of walkway section taken from second floor opening. Walkway section still remained as a piece-form[4].

Fig. 6.2: Photo of one of the walkway cross-beam[4].

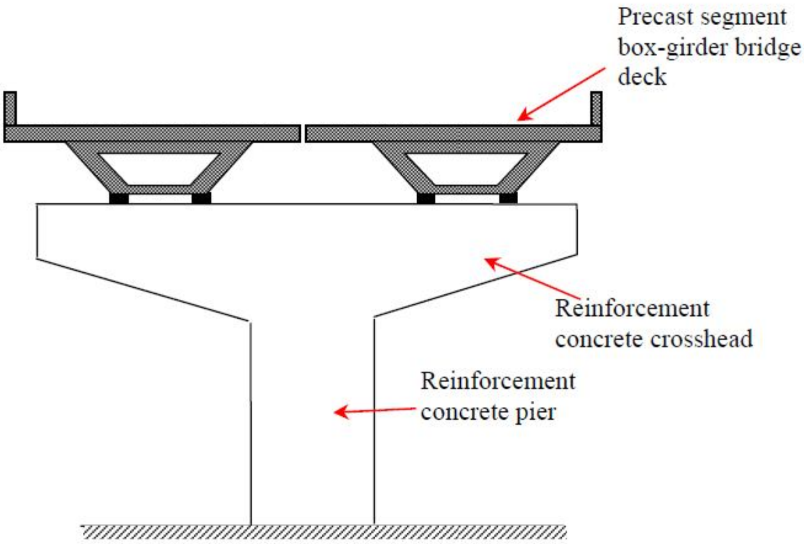


Fig. 6.3: Cross section of Flyover Bridge[4].

Fig. 6.4: Crack Pattern in Bridge[4].

CHAPTER 7

CONCLUSION AND RECOMMENDATION

7.1 INTRODUCTION

The proposed forensic framework has been developed to help local engineers in investigation of failure. The framework can determine all outline necessary to conduct the investigation into the causes of collapse and failure of buildings in the Gaza Strip the level of both the contractor, engineer and the owner. The framework consists of five stages: the first stage is the preliminary stage, the second stage is the stage of collecting evidence, the third phase, a phase of analysis and failure hypotheses, the fourth stage is the stage of final failure hypotheses and collapse, fifth stage is the stage of determining responsibilities failure. The stages consist of steps to contain many of the events which are comprised of a variety of tasks where this framework has been activated through several case studies of local and global systems.

The study seeks fulfilling this gap by suggesting a forensic framework in an effort to approach legal issues tied to the construction process of concrete buildings, with the Gaza Strip as a particular case.

The methodology adopted therefore uses three failure case studies; one is in the Gaza Strip whilst the other two are international, which serves validating the forensic framework, established for civil engineering cases within the Gaza Strip while comparing the latter to other existed frameworks.

The main output of the current study is to suggest a framework that include identifications of all types of collapses and failures in concrete buildings in the Gaza Strip as well as highlighting some of the major and minor responsibilities of failures.

The effective forensic framework has the following characteristics:

5- Simplicity and straightforwardness;
6- Touch upon the main causes of failure occurred in the Gaza Strip;

7- Relevance to all causes of failure in reinforced concrete structure; and
8- Marked by a small forensic team whose members stem from various institutions, in addition to being equipped with multi-disciplinary technical backgrounds.

The framework requires well-experienced and highly qualified forensic engineers in an effort to assess conditions of the structure, identify the causes of damage and determine acts that lay the template for the failure, thereby enabling the following objectives:

4- Asses the conditions of the structure followed by identifying the failures;
5- Focus on the causes of damage; and
6- Outline major and minor responsibilities of the failure.

7.2 RECOMMENDATION

1- It is recommended to use the proposed forensic framework for investigation in existing buildings in the Gaza Strip and study its applicability in the west bank and other countries with similar situations.

2- Various institution in the Gaza Strip such as arbitration centres encouraged to use the proposed framework with guide lines to prepare a full technical reports of collapse.

3- Further research on establishing forensic foundation engineering in the Gaza Strip.

4- Further research on establishing forensic infrastructure engineering in the Gaza Strip.

5- Further research is need on mitigation measures related to existing types of failures in the Gaza Strip cased by design faults and construction error.

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