Islamic University of Gaza
High Studies Deanery
Faculty of Engineering
Civil Engineering Department
Rehabilitation and Design of Structures

الجامعـــة الإســـلامية - غـــزة
عمـــادة الدراســـات العليـــا
كليـــــــــة الهندســـــــــة
قســـم الهندســـة المدنيـــة
برنامج تأهيـل وتـصميم المنـشآت

Rehabilitation Needs for Existing Buildings In Gaza Strip

احتياجات تأهيل المباني القائمة في قطاع غزة

By

Iyad Mohamed Abu Hamam

Supervised By

Assoc. Prof. Mohamed Ziara

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering –Rehabilitation and Design of Structures

November, 2008

ABSTRACT

The undertaken research work includes the development of a new approach for assessment of the rehabilitation needs for existing buildings that is suitable for use in Gaza Strip. The approach is simple, straightforward and cost effective. It is directed to the main types of damage in Gaza Strip, and can be used for all assessment requests. Although it can be implemented by a small team from various institutions with various technical backgrounds, it complies with the latest development in the worldwide rehabilitation standards. The approach has been developed after revision of international assessment approaches, especially the American and European approaches. Also local assessment practice has been evaluated in addition to a survey of the encountered damages in Gaza Strip that enabled identifying, grouping, and classifying such damages. The approach uses a planned regime of inspection and testing with efforts proportional to the cause, type, and extent of damage. It consists of three routes for assessment based on the damage extent. ***Route 1:*** Excessive Damage, ***Route 2:*** Minor Defects and ***Route 3:*** Moderate Damage. The routes consist of steps having several activities which have several tasks.

The results from the undertaken research work have shown that damages in existing buildings in Gaza Strip are mainly due to environmental conditions which resulted in deterioration of concrete and corrosion of steel reinforcement. Also other damages are associated with design and construction errors, poor quality concrete, fire accidents and Israeli military attacks. The developed assessment approach has been implemented considering nine real life case studies with various assessment causes, damage types and extents. The approach has proved its suitability for use in Gaza Strip and showed that if it was applied to previously assessed cases, different results would have been expected with more rational and economical solutions.

ملخص البحث:

يقدم هذا البحث اقتراحاً لطريقة جديدة مناسبة لتقييم احتياجات تأهيل المباني القائمة فـي قطـاع غزة. وتتميز الطريقة المقترحة بأنها بسيطة، مباشرة، وغير مكلفـة، وهـي موجهـة للأنـواع الرئيسية للأضرار في المباني القائمة في قطاع غزة، كما أنها من الممكن استخدامها فـي كافـة الحالات. وبالرغم من إمكانية تطبيقها بواسطة فريق صغير من مختلف المؤسـسات وبمختلـف الخلفيات التقنية إلا أنها تواكب التطورات العالمية الأخيرة في مواصفات ترميم المباني القائمـة. وتستخدم الطريقة المقترحة نظاماً مخططاً للتفتيش والفحص باستخدام جهود تتناسب مـع سـبب ونوع ودرجة الضرر، وتتكون من ثلاث مسارات: المسار الأول في حالة الضرر البالغ؛ المسار الثاني في حالة الضرر البسيط؛ والمسار الثالث في حالة الضرر المتوسط. وتتكون المـسارات من خطوات تحتوي على العديد من الفعاليات التي تتكون بدورها من العديد من المهام. وقد تـم تطوير هذه الطريقة بعد مراجعة العديد من طرق التقييم العالمية وخصوصاً الطرق الأمريكيـة والأوروبية، كما تم تقييم التطبيقات المحلية المتبعة في التقييم بالإضافة إلـى دراسـة مـسحية للأضرار المكتشفة في المباني القائمة في قطاع غزة.

وأظهرت نتائج هذا البحث أن الأضرار في المباني القائمة بقطاع غزة حدثت بشكل أساسي تبعاً للظروف البيئية التي تسببت في تدهور الخرسانة وصدأ حديد التـسليح. هـذا بالإضـافة إلـى الأضرار الأخرى الناجمة عن أخطاء التصميم والتنفيذ، الخرسانة غير الجيدة، حوادث الحريق، والهجمات العسكرية الإسرائيلية. وبعد أن تم التحقق من قابلية الطريقة المقترحة للتطبيق العملي من خلال تطبيقها على تسع حالات دراسية سابقة بمختلف أسباب التقييم وأنواع الضرر وشدتها فقد أثبتت الطريقة المقترحة مناسبتها للاستخدام في قطاع غزة كما أظهرت أنها لو طبقت علـى حالات سابقة لأتت بنتائج مختلفة ذات حلول منطقية واقتصادية أكثر.

ACKNOWLEDGMENT

I extend my sincere appreciation to all persons who helped in making this thesis a real thing rather than a dream. Special thanks are to my supervisor Assoc. Prof. Mohamed Ziara, for his guidance, patience, and encouragement.

I would like to thank all my lecturers in the Islamic University from whom I learned much and developed my skills during my study period.

Finally I would like to thank all the institutions and firms who positively cooperated in facilitating my task and didn't hide any needed information regarding the case studies. Special thanks are to the Association of Engineers Chairman Dr. Osama El-Eisawi for his efforts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACI	:	American Concrete Institute
ASTM	:	American Society for Testing and Materials
BSI	:	British Standards Institute
CEN	:	European Committee for Normalization
EN	:	European Norm standards
ISO	:	International Organization for Standardization
LR	:	Literature Review
RC	:	Reinforced Concrete
RH	:	Relative humidity
SISD	:	Simplified Index of Structural Damage.
TC	:	Technical Committee

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Reinforced concrete structures are often exposed to many types of damages and deteriorations due to different causes and exposure conditions during their life cycle. These causes may be natural or manmade. Natural disasters, wars, conflicts, etc. normally result in sudden destruction, while long neglect, abuse, environmental factors, inadequate design, and construction, etc. result in progressive deterioration [1]. Both old and new concrete buildings need rehabilitation (repairing, restoration, protection, and/or strengthening) when suffering deteriorations, damages, defects, changes in use, and/or due to code upgrading. Repairs can range from the basic repair of a form-related defect, to the complex, rehabilitation of a load bearing structure [2].

Field studies carried out in Palestine in 1997 indicated that a large percentage of house buildings in Palestine suffered of structural and/or deterioration problems. There was a need to rehabilitate almost 30% of existing housing stock, while 45% of the existing housing stock could be extended [3].

1.2 REHABILITATION OF STRUCTURES

Rehabilitation of existing structures is the process of repairing or modifying a structure to a desired useful condition [4]. It involves the improvement of existing structures physical condition through repair, restoration, protection, and/or strengthening after defects are encountered [5].

1.2.1 Causes for Rehabilitation

Sudden destruction or progressive deterioration of buildings would result in damages that need rehabilitation or replacement. Rehabilitation of structures is one of the fastest growing areas of engineering. The adverse influence of environmental factors after long neglect and the demand of increasing load levels have led to problems in load carrying capacity and long term durability of many structures. Furthermore, there are many structures that require either rehabilitation or demolition because of inadequate design/detailing, poor construction practice, natural or manmade destruction, etc. The replacement of every structure which showed signs of deterioration or that did not comply with requirements of present day loading levels, would be unthinkable both practically and economically [1].

1.2.2 Rehabilitation Needs

It is necessary that a thorough investigation of the nature and extent of the damage be carried out by appropriate professionals. The objective must be to treat the causes as well as the symptoms. Successful rehabilitation of damaged or deteriorated concrete structures requires professional assessment, design, management, and execution of a technically correct concept all in accordance with the highest quality standards [6]. Uniform design procedure for repair and strengthening of existing structures still, however does not exist. Some countries are in the process of developing relevant repair standards and specifications, for example European repair standards are now under development [7].

The decision on whether to rehabilitate or demolish a damaged structure is dependent on the anticipated functional life span requirements of the structure and the availability of cost-effective structurally upgrading solutions [1].

1.2.3 Advantages and Difficulties of Rehabilitation

Rehabilitation of existing structures has many advantages over the construction of new buildings. Rehabilitation may be preferred for various reasons including [1]:

- a- It is normally cheaper than demolition and new construction.
- b- It requires fewer raw materials thus saving natural resources.
- c- Rehabilitation is normally quicker.
- d- Existing buildings may be in better locations.
- e- Worldwide experience has demonstrated that rehabilitation provides more returns on investment.

Rehabilitation of damaged structures may, however have some difficulties including [1]:

- a- The need to evaluate the material and structural characteristics of the existing damaged structure related to load carrying capacity and durability.
- b- Lack of standard design and analysis method which can be readily applied to rehabilitated structures.

c- Architectural and use constraints related to existing spaces, location of structural elements, and configuration.
d- Limitation of relevant practical experience.
e- Difficulties in specifying and management or rehabilitation works.

1.3 GAZA STRIP PARTICULARITY

Gaza Strip is a coastal region located at the Mediterranean Sea. Normally, this location makes many reinforced concrete structures in the area susceptible to aggressive actions due to the high relative humidity and the high salts concentration in the atmosphere especially near the coast. These aggressive actions constitute a major factor in the corrosion of steel reinforcement which in turn causes many types of damages to existing structures. In addition, structures in Gaza Strip may face several defecting criteria in their life starting from their design stage to the service stage. These normally include faults in design, faults in the construction processes, defects in the materials, and chemical attacks, etc.

On the other hand Gaza Strip is an occupied region that faces violent invasion due the Israeli attacks by several types of manmade destructions such as destructive missiles and bombs that destroy buildings and cause multiple types of damage to existing structures.

Several local institutions and consulting firms in the Gaza Strip have carried out assessment studies of the damages in existing structures and proposed solutions to the problems. Each of these institutions has followed its own strategy and procedure to assess the faults, and has considerable case studies where various causes and types of damage were encountered.

Until now, there is a no national standard or nationally adopted assessment method in Palestine to be followed in the assessment and evaluations of existing structures regarding their structural strength, safety, and serviceability. Not only there is no collective database of the damages in concrete structures in the Gaza Strip regarding the causes, types, and severity, but also no general recommendations and guidelines are available to rehabilitate such damages.

This research is mainly concerned in studying available case studies information, classify the damages, identify the local assessment practice, and compare it with the international standards and guidelines for evaluation of existing concrete structures. This has lead to the development of an assessment method suitable for use in Gaza Strip.

1.4 RESEARCH SIGNIFICANCE

1.4.1 Research Importance

The research is concerned with surveying the spreading out and isolated information obtained by several local institutions that actually undergo evaluation and rehabilitation of existing reinforced concrete structures in the Gaza Strip. This collective database made it possible to group, study, and classify the damages in existing structures, find out their causes, and identify the used rehabilitation techniques. As a result, an assessment approach has been developed suitable for use in Gaza Strip.

1.4.2 Scope and Objectives

The scope of this research is to develop a unified procedure suitable for assessment of damages in reinforced concrete buildings in Gaza Strip and propose general rehabilitation techniques relevant to existing damages. The specific objectives are:

1- Develop a collective database of defects and damages in the existing reinforced concrete structures.
2- Investigate the local assessment practice and compare it with the international standard methods in order to overcome the shortcomings in local practice.
3- Develop a unified procedure for assessment of damages in existing reinforced concrete structures in Gaza Strip.
4- Propose rehabilitation techniques for repair of existing damages relevant to damage types faced in Gaza Strip.

1.4.3 Research Methodology

The objectives of the study have been achieved by implementing the following steps:

1.4.3.1 Literature Review

Various research works published in literature such as books, technical papers, reports, etc. were reviewed to identify the evaluation methods, assessment procedures, repair standards, strengthening, and rehabilitation techniques for damages in existing concrete structures. The implication of these studies on the prevailing conditions in Gaza Strip was considered.

1.4.3.2 Gathering Information

Several institutions and consulting firms that practiced evaluation and rehabilitation of existing structures in Gaza Strip such as The Association of Engineers, Islamic University Soil and Materials Laboratory, The Association of Engineers Materials Testing Laboratory, and selected engineering consulting firms, were visited and interviewed to get available information. Although some difficulties were found, several cases were reviewed and information regarding defects, deteriorations, damages, and assessment practice were classified.

1.4.3.3 Data Analysis

Gathered information which reflected the situation in Gaza Strip were studied and analyzed statistically to classify the damages in concrete structures in Gaza Strip according to the following categories:

1- Causes.
2- Structural severity.
3- Implemented strengthening and/or rehabilitation techniques.

1.4.3.4 Development of a Unified Assessment Process

Based on the available data and according to international standards and guidelines, a unified assessment approach has been developed and proposed for use in Palestine.

1.4.3.5 Verification of the Developed Approach

The approach suitability for use in Gaza Strip was verified by application of the approach to several cases with varying assessment levels and damage types.

1.4.3.6 Development of Assessment Manual

A Manual has been developed to serve as a guide for assessment and evaluation of existing structures at practical level. It describes the developed assessment approach, in addition to rehabilitation techniques for common damages that could be encountered in existing structures in Gaza Strip. The Manual is attached in annex A.

1.4.3.7 Conclusions and Recommendations

At the end of the research conclusions are judged and recommendations regarding the research outcome are made with remarks on further needed investigations and studies.

1.5 RESEARCH OUTCOME

The research contribution to the local engineering practice has been manifested in the following outcomes:

1. A new assessment approach developed for existing structures in Gaza Strip.
2. Identification of rehabilitation techniques relevant to the encountered damages in existing buildings and suitable for use in Gaza Strip.
3. A Manual including a full description of the developed assessment approach with the rehabilitation techniques related to the common damages in Gaza Strip existing buildings.

1.6 THESIS ORGANIZATION

The thesis contains seven chapters as follows:

Chapter 1 (Introduction): This chapter gives some background information regarding rehabilitation of existing structures, the Gaza Strip particularity; its location, environmental conditions, aggressive actions and background about the assessment and rehabilitation practice in Gaza strip. Also it gives a description of the research importance, scope, objectives, and methodology, in addition to the report organization.

Chapter 2 (Literature Review of Assessment and Evaluation Methods of Existing Structures): Among the several assessment approaches that were found in literature, important documents are summarized in this chapter. Also a description of local assessment practice used in Gaza Strip is included in addition to a discussion of the assessment methods with emphasis on their implication to Gaza Strip particularity.

Chapter 3 (Defects in Concrete Structures and Rehabilitation Techniques): This chapter includes a literature review on defects causes and types, in addition to some information regarding methods of repair of damaged concrete structures.

Chapter 4 (Case Studies Survey): A survey of actual case studies undergone by local institutions was made in order to study various aspects for rehabilitation of existing structures in Gaza Strip. The chapter describes the main findings of the survey, classification of the encountered damages with regard to their causes and types, and identification of the local assessment practice and evaluation procedures. The prevailing conditions in Gaza Strip were discussed and compared with various assessment methods and damages information to identify strong and weak points in local practice.

Chapter 5 (Proposed Assessment Approach for Existing Structures in Gaza Strip): Considering the various assessment methods, types of damages, and the current conditions in Gaza strip, an assessment approach was developed and proposed to be used in Gaza strip. This chapter gives a detailed description of the proposed approach, routes, steps, activities, and tasks. It comprised methods of assessment for all types of damages in Gaza strip existing buildings.

Chapter 6 (Verification of the developed Assessment Approach): This chapter describes the application of the approach on several case studies that were selected. These cases were of different types of damage with varying degrees of sophistication and assessment efforts. The purpose of the implementation is to verify the suitability of the approach for the prevailing conditions in Gaza Strip.

Chapter 7 (Conclusions and Recommendations): This chapter includes the concluded remarks, main conclusions and recommendations drawn from the research work.

CHAPTER 2: LITERATURE REVIEW OF ASSESSMENT AND EVALUATION METHODS OF EXISTING STRUCTURES

2.1 INTRODUCTION

The conditions of existing reinforced concrete (RC) constructions need to be evaluated periodically or in certain circumstances to insure the adequacy of structural elements to carry their imposed loading, and to verify soundness of the whole structure. The reasons for this arise from several factors such as:

1- The tendency of RC elements to deteriorate due to many factors and exposure conditions.
2- The need to upgrade or modify these structures.
3- Other accidental events and manmade destructions that may occur and cause distress or damage to buildings.

Before attempting any repair or rehabilitation of an existing building, it is necessary to have a planned approach of assessment to investigate its condition. While the diagnosis of damage or deterioration in some cases is reasonably straightforward, it may not be so in many other cases that will require a thorough technical inspection and an understanding of the behavior of the structural component under consideration. This task should be assigned to qualified expert engineers who can complete the assessment in a well managed process that results in accurate diagnosis and suitable remedy of the problem using the optimal approach for both assessment efforts and repair techniques[8].

Assessment of existing structures is an advanced and sophisticated engineering practice that reached a high degree of development and covered all related aspects of existing structures defects and deteriorations. Its importance is clearly understood in the huge heritage of deteriorating existing structures in the world that constitutes a considerable value of global economy. Efficient and economical repair of such structures occupied a large margin of research work all over the world, the matter that led to enormous knowledge in literature concerning assessment, evaluation, and repair of existing structures.

Existing structures constitute a great value in today's wealth and economy of nations, especially RC structures. These structures are usually designed for a life span extending over generations due to the excellent characteristics and durability of concrete. Unfortunately, these structures are subject to a range of degradation mechanisms, which result in the generation of defects. The nature of the deterioration mechanisms and the form of the structures often indicate that repair is necessary at a stage considerably before serious structural implications arise. This has, and will continue to, generate a legacy of demand for repair of structures that are still serviceable but suffer defects in durability, cosmetic or safety function [5].

A basic understanding of underlying causes of concrete deficiencies is essential to performing meaningful evaluations and successful repairs. If the cause of a deficiency is understood, it is much more likely that an appropriate repair system will be selected, and that, consequently, the repair will be successful and the maximum life of the repair will be obtained. Symptoms or observations of a deficiency must be differentiated from the actual cause of the deficiency, and it is imperative that causes and not symptoms be dealt with wherever possible or practical. Only after the cause or causes are known, rational decisions can be made concerning the selection of a proper repair system [9].

2.2 DEFINITION OF ASSESSMENT OF EXISTING STRUCTURES

The International Organization for Standardization Technical Committee 71 (ISO TC 71) defines the assessment as: "A set of activities performed in order to verify the reliability of an existing structure for future use" [10]. This compact and comprehensive definition can be expanded and explained for the purpose of this research, to define the assessment of existing structures as: "A planned regime of inspection and testing of the structure by suitably experienced and qualified engineers to know the condition of the structure and to understand the cause or causes of deterioration so that the subsequent repair strategy is appropriate for both rectifying the existing defects and resisting future deterioration"[5].

A proper assessment will include surveying of the current condition of the structure, diagnosis of the causes of defects or deterioration, defining remedial actions to be carried out, and selecting the most appropriate intervention action according to the condition of the structure and the owner's requirements [11].

2.3 NEEDS FOR ASSESSMENT AND EVALUATION OF EXISTING STRUCTURES

Many existing concrete structures or structural elements are subject to corrosion and fatigue which are usually the main deterioration processes [12]. Also impact, earthquake or wind storms can result in structural damage. Concerns about the correct design and construction of existing structures, including low quality building material or workmanship are sometimes sufficient reasons to conduct the assessment. Spalling, cracking, and degraded surface conditions are typical indications of deterioration.

In particular, serviceability and safety of existing structures need to be evaluated for a variety of reasons such as [12]:

1. Changes in use, changes in code provisions and regulations, or increase of loads.
2. Effects of deterioration mechanisms.
3. Damage resulting from extreme loading events.
4. Concern about design or construction errors, and about the quality of building material and workmanship.

2.4 APPROACHES FOR ASSESSMENT AND EVALUATION OF EXISTING STRUCTURES

There are numerous references describing methods for investigating the condition of a structure. These include methods presented by the International Standards Institutions e.g. American Concrete Institute (ACI), British Standards Institute (BSI), International Organization for Standardization (ISO), European Norm standards (EN1504), and European projects manuals such as: CONTECVET [13,14,15], NORECON [16,17,18], REHABCON [19], BRIME [20], and others. All of these documents adopt a planned regime of investigation for existing structures with variable levels of complexity according to the situation and the structure importance.

The investigation process may involve a preliminary visual survey, followed by more detailed inspection and testing to determine the cause and general extent of deterioration. Depending on these findings, further investigation and testing may be required perhaps to identify specific boundaries of deterioration or potential deterioration. The information gathered during the investigations is used to provide an understanding of the mechanisms that cause deterioration, the severity and extent of defects, and the implications for repair or other rehabilitation strategies [5].

Several assessment approaches are available in literature. These approaches were adopted by the international standards and European rehabilitation manuals. Most of them are similar in principle, but vary in the steps. While some approaches start from the basics, others are continuations from where a previous assessment method ended. A summary of these assessment approaches is given to show the up to date information available regarding this topic as follows:

2.4.1 American Concrete Institute Approach

Several interrelated ACI documents concerning the assessment and evaluation of existing structures are available. Among these documents the following were selected to highlight assessment various aspects such as: making a condition survey of concrete in service [21], evaluation of existing structures prior to rehabilitation [22], and strength evaluation of existing concrete buildings [23].

2.4.1.1 Guide for Making a Condition Survey of Concrete in Service [ACI-201.1 R-92 (1997)]

Any investigation of an existing building requires a condition survey of the structure. The ACI 201.1 R-92 (1997) "Guide for Making a Condition Survey of Concrete in Service" [21] presents a system for making a condition survey of concrete in service to identify and define areas of distress. The system is designed to be used in recording the history of a project, and describe the deteriorations of a structure in systematic manner that facilitates diagnosis of their cause or causes.

The guide also provides a check list containing items of the needed information through which the personnel conducting the condition survey can select specific items important and relating to the reasons for the survey. The check list contains detailed sequence of the following items:

1. Description of structure.
2. Overall alignment of structure: settlement, deflection, expansion etc.
3. Portions showing distress: beams, columns, walls, etc.
4. Surface condition of concrete: cracks, spalls, popouts, leaching, etc.

5. Interior condition of concrete: strength, density and moisture content of cores, evidence of alkali-aggregate or other reaction, bond to aggregate, reinforcing steel, chloride-ion content, cover to reinforcing steel, and depth of carbonation, etc.
6. Nature of loading and detrimental elements.
7. Materials of construction.

The most important in this reference is that distress manifestations were categorized and illustrated by photographs. Their severity and extent of occurrence were quantified where possible. This was an attempt to standardize the reporting of the condition of the concrete in a structure, and to make those performing the survey thoroughly familiar with the various types of distress and the rating scheme before starting the survey [21].

2.4.1.2 Guide for Evaluation of Concrete Structures Prior to Rehabilitation [ACI 364.1-R-94 (1999)]

This report outlines procedures that may be used for evaluation of concrete structures prior to rehabilitation [22]. The evaluation work is generally performed for one or several of the following purposes:

1. To determine the feasibility of changing the use of a structure, retrofitting the structure to accommodate a different use from the present one, and/or enlarging the structure or changing the appearance of the structure.

2. To determine the structural adequacy and integrity of a structure or selected elements.

3. To evaluate the structural problems or distress resulting from unusual loading or exposure conditions, inadequate design, or poor construction practices. Distress may be caused by overloads, fire, flood, foundation settlement, deterioration due to abrasion, fatigue effects, chemical attack, weathering, and/or inadequate maintenance.

4. To determine the feasibility of modifying the existing structure to conform to current codes and standards.

The assessment procedure adopted in this report is summarized into two phases, preliminary investigation and detailed investigation as follows [22]:

a- Preliminary Investigation:

The assessment of existing structures starts normally with a preliminary investigation which is typically introductory in nature and not comprehensive. It aims to provide initial information regarding the condition of the structure, the type and seriousness of the problems affecting it, the feasibility of performing the intended rehabilitation, and information on the need for a detailed investigation. They commonly identify the need for a more detailed or extensive study and for an additional scope of services. However, in some cases, the preliminary investigation may determine that it is not desirable to proceed with a further detailed investigation, as in the case of excessive damage where the structural integrity cannot be economically restored or the owner's objectives cannot be satisfactorily met.

The scope and methodology of a preliminary investigation can involve one or more of the following steps, depending on the size and complexity of the project:

1. Review of plans, specifications, and construction records.
2. Site observations of conditions.
3. Measurement of geometry, deflections, displacements, cracks, and other damage.
4. Nondestructive testing.
5. Exploratory removal.
6. Sampling, testing, and analysis.

It should be noted that only a limited amount of investigation within each step is generally required to establish the feasibility of the rehabilitation project. Detailed studies are generally deferred until the detailed investigation phase, if such investigation is deemed desirable.

The results of the preliminary investigation should be summarized in a report that will generally include structural capacity check, project feasibility, identification of structural problems, strengthening requirements, and needs for further investigation [22].

b- Detailed Investigation:

The detailed field investigation should only be performed after the preliminary investigation is completed, the owner's goals identified and tentatively determined to be feasible, and the objectives of the detailed investigation properly defined. It is important before proceeding with the detailed investigation that the project budgets and costs of the detailed investigation be approved by the owner.

The detailed investigation may be divided into the following five major tasks:

- Task 1. Documentation.
- Task 2. Field observations and condition survey.
- Task 3. Sampling and material testing.
- Task 4. Evaluation.
- Task 5. Final report.

Tasks 1, 2, and 3 constitute the findings of the preliminary investigation that will directly influence the final outcome of the evaluation process, the choices of various rehabilitation methods to be considered, the estimated cost associated with each rehabilitation alternative, and ultimately the selection of the appropriate rehabilitation method.

The evaluation (Task 4) is a process of determining the adequacy of a structure or component for its intended use by analyzing systematically the information and data assembled from reviews of existing documentation, field inspection, condition survey, and material testing. The number and type of steps vary depending on the specific purpose of the investigation, the type and physical condition of the structure, the completeness of the available design and construction documents, and the strength and quality of the existing construction materials.

In general, the evaluation process shall consist of, but not limited to:

1. Architectural considerations.
2. Materials Evaluation.
3. Structural evaluation.
4. Evaluation of rehabilitation alternatives.
5. Cost evaluation.

In Task 5, a comprehensive report is issued containing the results of the entire investigation. This report generally includes a brief description of the following basic areas addressed during the evaluation process:

1. Purpose and scope of investigation.
2. Existing construction and documentation.
3. Field observations and condition survey.
4. Sampling and material testing.
5. Evaluation.
6. Findings and recommendations [22].

2.4.1.3 Strength Evaluation of Existing Concrete Buildings [ACI 473 R-03]

This report provides recommendations to establish the loads that can be sustained safely by the structural elements of an existing concrete building [23]. It covers all types of structural concrete. The recommended procedures in this report apply where strength evaluation of an existing concrete building is required in the following circumstances:

1. Structures that show damage from excess or improper loading, explosions, vibrations, fire, or other causes.
2. Structures where there is evidence of deterioration or structural weakness, such as excessive cracking or spalling of the concrete, reinforcing bar corrosion, excessive member deflection or rotation, or other signs of distress.
3. Structures suspected to be substandard in design, detail, material, or construction.
4. Structures where there is doubt as to the structural adequacy and the original design criteria are not known.
5. Structures undergoing expansion or a change in use or occupancy and where the new design criteria exceed the original design criteria.
6. Structures that require performance testing following remediation (repair or strengthening).
7. Structures that require testing by order of the building official before issuing a Certificate of Occupancy.

The document presents the following evaluation steps:

1. Conducting preliminary investigation to define the existing condition of the building, including:
   - a- Reviewing available information.
   - b- Conducting a condition survey.
   - c- Determining the cause and rate of progression of existing distress.

d- Performing preliminary structural analysis.

e- Determining the degree of repair to precede the evaluation.

2. Selecting the structural elements that require detailed evaluation.
3. Assessing past, present, and future loading conditions to which the structure has and will be exposed under anticipated use.
4. Conducting the evaluation.
5. Evaluating the results.
6. Preparing a comprehensive report including description of procedure and findings of all previous steps [23].

2.4.2 European Approaches for Assessment

Extensive European work has been found in literature, several projects were concerned in evaluation and rehabilitation of existing structures. The outcome of these projects constituted a number of manuals and European standards for repair of existing structures. The following is a summary of the most recognized assessment methods adopted in these documents.

2.4.2.1 CONTECVET "A Validated User's Manual for Assessing the Residual Service Life of Concrete Structures"

CONTECVET project was concerned with assessing the residual service life of deteriorating concrete structures. The project was completed in 2000, with the principal outputs being four Manuals, covering deterioration due to corrosion, frost action, alkali silica reaction, and the leaching of concrete.

The main stages to accomplish the assessment process are: inspection and testing on-site, diagnosis of the cause of damage and its effect on structural performance, and prediction of the development of the damage and the structural consequences.

The manuals are based on the principle of progressive screening, with the investigation proceeding only as far as is necessary to obtain a reliable estimate of capacity and to determine with confidence whether any intervention is required. The assessment methodology is framed in two levels: The Simplified and The Detailed Methods [19]:

a- The Simplified Method is a qualitative approach, based on establishing a ranking of element performance, their actual state, and a suggestion on the urgency of intervention. This methodology is specially suggested for owners with great amount of elements and structures to be quickly and efficiently assessed, using after it (if required) a detailed method for the assessment of each element. It is also adequate when it is necessary to make a preliminary assessment of a singular structure. The procedure has been developed mainly for common building structures and should be seen as a procedure for establishing priorities in an extensive structural heritage, by means of a rational and quick process.

The main tasks to be carried out during the simplified method are divided into three steps that are sequenced in time. The first one is a complete inspection of the structure that allows knowing the data needed for the input in the second task, which is the assessment phase. Finally, the prognosis about the structural performance is made through the data available from the assessment. Figure 2.1 shows the main steps and their results in the simplified methodology.

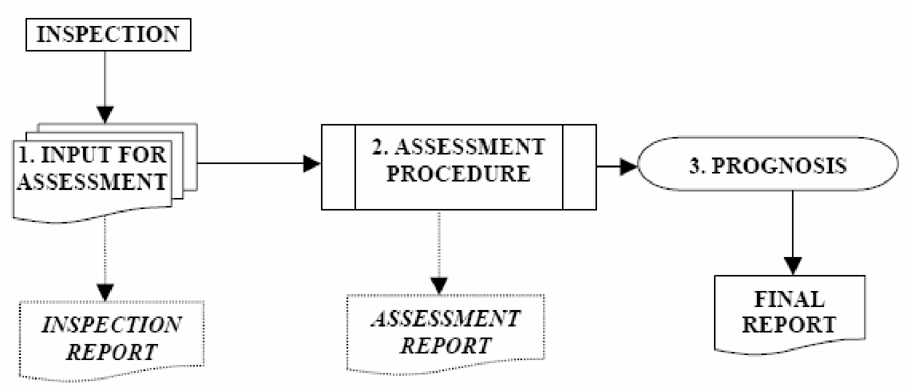


Fig. 2.1: General Overview of CONTECVET Simplified Assessment Method [13].

The inspection phase aims to the collection of data necessary for calculating the Simplified Index of Structural Damage (SISD). It consists of three main actions that can be developed simultaneously:

1. A Preliminary visual inspection.
2. Desk work.
3. In-situ testing.

The assessment of the structure may be divided in two main aspects, the present estate (diagnosis), and its future evolution (prognosis). The purpose of the diagnosis phase consists in the appraisal of present performance of the structure in a simplified semiempirical manner, based on the data collected during the inspection of the structure. The prognosis phase is established as an urgency of intervention classification [13].

b- The Detailed Method is a quantitative structural assessment of the impact of deterioration on individual action effects such as bending, shear, bond, etc. It has been developed for a rigorous assessment procedure by element taking into account the composite steel–concrete behavior, as is common practice in structural designing procedures. Thus, the information and data required are, in fact, more numerous, all information needed for achieve the final safety margin of the element should be obtained from the inspection phase. This information must contain not only which regards structural performance, but also the information leading the deterioration process (typology, extension, reasons for deterioration, etc.). This methodology can be applied in bridge elements (piers, beams, deck, abutments, etc.) and also in building elements and is based in the quantification of the reduction in load bearing section of the concrete and steel. The prediction of future evolution is based on the measurement of the deterioration rate [13].

Both of the two methods are considered to be completely operational by themselves [19]. The decision of use each type of assessment should be based on several criteria such as:

1. Aim and importance of the assessment.
2. Amount of elements to be assessed.
3. Damage extension.
4. Previous results of other inspections.
5. Amount of information needed.
6. Economical reasons.

The main aspects of the assessment of a deteriorating structure according to CONTECVET manuals include:

1. The need to establish the level of present performance by establishing the type, extent and cause of the damage.
2. The establishment of the average rate of deterioration.
3. The prediction of the loss of the structural capacity.
4. The identification of the minimum acceptance level of performance.
5. The urgency of intervention.

Detailed procedures for assessment of existing concrete structures can be referred to in the CONTECVET manuals for the main four mechanisms of deterioration [19]:

1. Reinforcement corrosion [13].
2. Alkali Silica reaction.
3. Frost attack: salt scaling and internal damage [14].
4. Leaching [15].

2.4.2.2 REHABCON "Strategy for Maintenance and Rehabilitation in Concrete Structures"

REHABCON is concerned with developing a management system for the maintenance and rehabilitation of the existing concrete infrastructure. Since it continues on from the CONTECVET project, REHABCON is based on the principles outlined and developed through this previous project. The objective of REHABCON is to provide a strategy for the repair and rehabilitation of the concrete infrastructure. The end product is a comprehensive and practical manual which can be used to enable decisions to be made on the management of deteriorated concrete structures. Strong emphasis is put on performance criteria, based on whole life costing, and the principles of life cycle analysis and sustainability [19].

REHABCON identifies the performance requirements that need to be taken into account in determining the range of potential repair options. In addition, the main requirements to be fulfilled are defined and reviewed. These include technical requirements (service life, durability, structural stability and safety, execution of work, and maintenance requirements) in addition to non-technical issues (environmental, health, social, political and legal). After establishing a number of intervention actions and repair options, the manual presents principles and tools to be used in the evaluation of repair alternatives taking into consideration all the technical and non-technical requirements describing several methods that can be used for the selection and optimization of the rehabilitation strategy including Life Cycle Cost Analysis, and the Repair Index Method [19].

Fig. 2.2 illustrates the main features of the assessment methodology adopted in REHABCON. These include five main tasks as follows:

Task 1. Assessment: to determine the cause and type of damage, the impact of damage on the structure, suggest the intervention action, and report complete assessment data, calculations and tests.

Task 2. Analysis of basic requirements of the structure.

Task 3. Selection of a few repair principles, main repair methods and systems.

Task 4. Evaluation of repair methods and preparation for the decision process.

Task 5. Make decision.

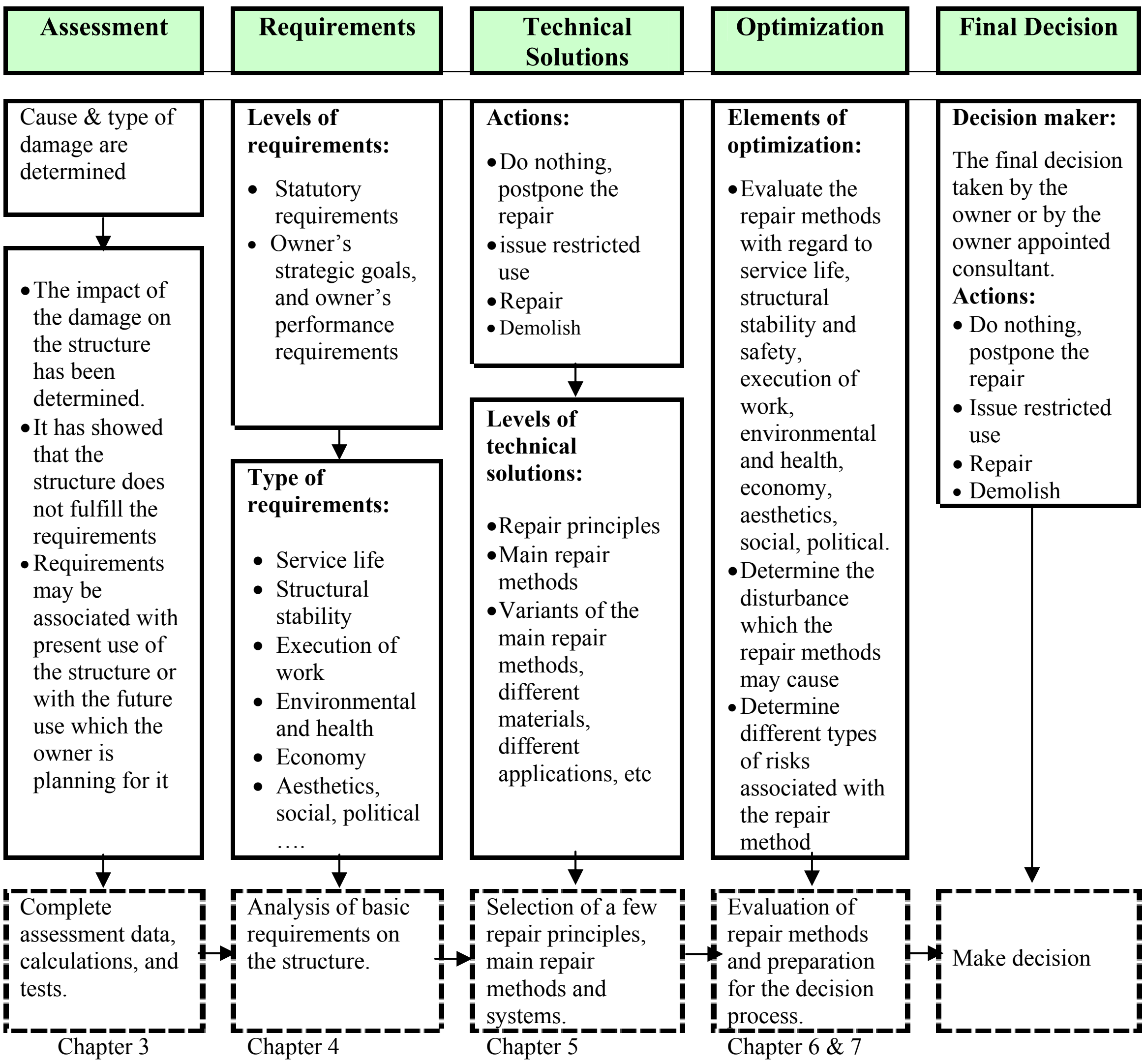


Fig. 2.2: Repair Process of REHABCON Manual (Reproduced after [19]).

2.4.2.3 Products and Systems for the Protection and Repair of Concrete Structures EN-1504

Great effort was made to work out a European Standard on protection and repair of concrete structures. Actually the European Countries are preparing to replace the existing national standards and recommendations by the new European Standard EN-1504 which provides a comprehensive set of European standards for concrete repair [24]. The structure of the standards is shown in Table 2.1:

Table 2.1: Contents of European Standard EN-1504 [25]

Part number	Part Title	Current Status
Part 1	General Scope and Definitions	Published in 1998
Part 2	Surface protection systems.	Published in October 2004
Part 3	Structural and non structural repair.	Out for Formal Vote within CEN
Part 4	Structural bonding.	Published in November 2004
Part 5	Concrete injection.	Published in December 2004
Part 6	Grouting to anchor reinforcement or to fill external voids	Under development
Part 7	Reinforcement corrosion prevention.	Out for CEN Enquiry
Part 8	Quality control and evaluation of conformity.	Published in November 2004
Part 9	General principles for the use of products and systems.	Published in 1997
Part 10	Application of products & systems and quality control of the works.	Published in December 2003

Part 9 of EN-1504 adopts a methodology for assessment and repair of existing structures consisting of five main steps, as shown in Fig. 2.3:

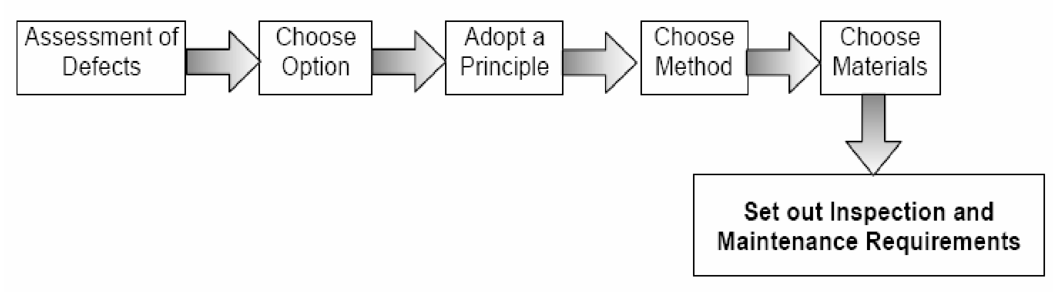


Fig. 2.3: Logic of EN-1504 [5].

Table 2.2 sets out the process of assessment, specification, site execution, maintenance and monitoring as described in the standard:

Table 2.2: EN-1504 Process of Assessment [25]

<table>
<tr><td>Step 1
Assess damage
Clause 4</td><td colspan="2">• Present condition
• Original design approach
• Environment and contamination
• Conditions during construction
• Conditions of use
• History of structure
• Future use</td></tr>
<tr><td>Step 2
Choose Options
Clause 5</td><td colspan="2">• Considering intended use, design life and service life with the required performance characteristics
• Likely long-term performance of protection or repair works
• Opportunities for additional protection and monitoring
• Acceptable number and cost of future repair cycles
• Cost and funding of alternative protection or repair options, including future maintenance and access costs
• Properties and methods of preparation of existing substrate
• Appearance of protected or repaired structure</td></tr>
<tr><td>Step 3
Choose Principle(s)
Clause 6</td><td>Defects in Concrete
1. Protection against ingress.
2. Moisture control.
3. Concrete restoration.
4. Structural strengthening.
5. Physical resistance.
6. Resistance to chemicals.</td><td>Reinforcement corrosion
7. Preserving or restoring passivity.
8. Increasing resistivity.
9. Cathodic control.
10. Cathodic protection.
11. Control of anodic areas.</td></tr>
<tr><td>Step 4
Choose Method(s)
Clause 6</td><td colspan="2">• Appropriate to type and cause or combination of causes and to the extent of the defects
• Appropriate to future service conditions
• Appropriate to protection or repair option chosen
• Compliance with the Principle chosen
• Availability of products and systems complying with the EN 1054 series or any other relevant EN or European Technical Approval</td></tr>
<tr><td>Step 5
Choose Materials
Clause 7</td><td colspan="2">• Characteristics for all intended uses
• Characteristics for certain intended uses
• Characteristics may be considered for specific Applications</td></tr>
<tr><td>Step 6
Specify ongoing requirements
Clause 8</td><td colspan="2">• Record of the protection or repair works which have been carried out
• Instructions on inspection and maintenance to be undertaken during the remaining design life to the repair part of the concrete structure</td></tr>
</table>

Step 1: "Assessment of Damage" that aims to [24]:

1. Identify the cause or causes of defects.
2. Establish the extent of defects.
3. Establish where the defects can be expected to spread to parts of the structure that are at present unaffected.
4. Assess the effect of defects on structural safety.
5. Identify all locations where protection or repair may be needed.

The rules for the use of products and systems for protection and repair of concrete structures are based on a hierarchy of different levels, namely options, principles and methods as described in the following steps [24]:

Step 2: "Choose Options" among the following options that shall be taken into account in deciding the appropriate action to meet the future requirements for the life of the structures:

1. Do nothing for a certain time.
2. Re-analysis of structural capacity, possibly leading to downgrading of the function of the concrete structure.
3. Prevention or reduction of further deterioration, without improvement of the concrete structure.
4. Improvement, strengthening or refurbishment of all or parts of the concrete structure.
5. Reconstruction of part or all of the concrete structure.
6. Demolition of all or part of the concrete structure.

Step 3: "Choose Principle(s)" from the defined different principles for repair and protection of damages to the concrete and damages induced by reinforcement corrosion. Tables 2.3 and 2.4 respectively show the six principles for protection and repair of concrete, with the five principles to prevent damages due to reinforcement corrosion.

Table 2.3: EN-1504 Principles for Repair and Protection for Damages [24]

Principle No.	Principle and its definition
Principle 1 (PI)	Protection against Ingress
Principle 2 (MC)	Moisture Control
Principle 3 (CR)	Concrete Restoration
Principle 4 (SS)	Structural Strengthening
Principle 5 (PR)	Physical Resistance
Principle 6 (RC)	Resistance to Chemicals

Table 2.4: EN-1504 Principles for Protection against Reinforcement Corrosion [24]

Principle No.	Principle and its definition
Principle 7 (RP)	Preserving or Restoring Passivity
Principle 8 (IR)	Increasing Resistivity
Principle 9 (CC)	Cathodic Control
Principle 10 (CP)	Cathodic Protection
Principle 11 (CA)	Control of Anodic areas

Step 4: "Choose Method(s)" to protect or repair a concrete structure according to the principles chosen in step 3 from different methods available. Thirty seven methods for protection and repair are described within EN-1504-9.

Step 5: "Choose materials" using the predefined EN-1504-9 performance characteristics for every repair method for intended uses. The designer selects the performance characteristics based on the requirements of the special repair project and the selected repair methods.

2.4.2.4 NORECON "Network on Repair and Maintenance of Concrete Structures"

NORECON Manual constitutes collective information of European previous work covering all relevant aspects regarding maintenance and repair of concrete structures. It consists of the following three technical tasks:

Task T1: Decisions and requirements for repair

Task T2: Repair Methods

Task T3: Pre-normative work

The methods and procedures for assessment in NORECON are based on European previous work such as: CONTECVET and EN-1504. It comprises four levels of assessment [16]:

Level 1*:* On basis of a visual inspection decide whether the structure suffers significant deterioration or change.

Level 2: In case significant deteriorations have occurred, perform a desktop study based on background information and visual inspections. The desktop study is used as a basis for the assessments made on the next two levels.

Level 3: Perform a preliminary assessment of the structural stability and serviceability. The preliminary assessment is based on the desktop study on Level 2, and on limited testing of the structure. At this level, the estimation of structural safety can be based on a semi-qualitative simplified judgment system of some type, entirely based on information that is easily obtained from the structure. In many cases a Level 3 assessment might be sufficient for estimation of whether a structure shall be repaired or not. Therefore, Level 3 is well suited for rating a population of similar structures, thereby giving priority to structures that must be taken care of immediately and sorting out structures for which repair can wait. Level 3 assessment can also be used for decisions on how and what to repair provided damage is not too serious.

Level 4: In most cases a reasonably correct assessment of safety and serviceability must be based on a detailed investigation with in-situ testing of the structure, including measurements of corrosion rate and residual strength in representative sections, real dimensions of cross-sections, etc. Besides, by such investigations the cause of damage must be clarified beyond doubt. Assessment on level 4 can be characterized as a structural re-design. A Level 4 assessment of the actual status is in many cases fairly easy, provided all relevant data are available. A safe extrapolation of the future status is much more difficult. It requires good knowledge of the time process of all destructive mechanisms and a possibility to estimate as exactly as possible the future climatic conditions.

The final decision on if and how to repair shall be based on:

1. A condition assessment.
2. An analysis of basic requirements on the structure.

3. A priority ranking.
4. A thorough analysis of suitable repair principles.
5. A final selection of optimum repair method [16].

2.4.2.5 International Organization of Standardization Assessment Method

The ISO standard TC-71/SC-7/WG-2 gives the requirements for condition assessment of concrete structures, including a format for documentation of the deterioration causes, the extent of the deterioration, and consequences. Fig. 2.4 shows the main parts of a condition assessment [10].

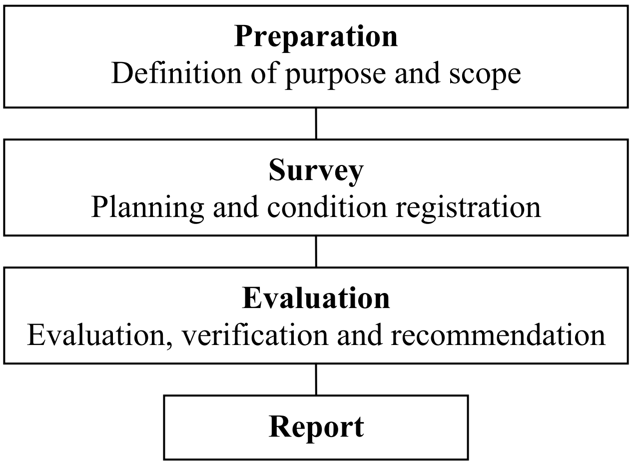


Fig. 2.4: Main Parts of the ISO Condition Assessment [10].

The condition assessment includes a description of the structure, the investigation, the results, the expected future development, and a short presentation of possible repair principles and methods including appropriate cost calculations. It can be performed according to this standard in the following four steps:

Step 1: Preparation

To perform a condition assessment good preparation includes clear definition of the scope of assessment, the assessment level to be achieved, the object to be assessed, the parties involved in the survey and evaluation, and their responsibilities. This should be given in a project specification including a description of the work to be carried out, what the report should include, cost, and time, etc.

Step 2: Survey

This step consists of two consecutive sub-steps: planning and condition registration. The planning includes all preparatory work to be done by the inspector in order to carry out the assessment according to the purpose and scope of the condition assessment. It shall be decided if a visit to the structure is necessary before doing the planning. Original information of the structure like drawings, calculations and as built information shall be evaluated, if possible.

The following sub-step is the condition registration which is a systematic collection of information, observations and test results. It consists of the information from construction and operation, the observations on site, the results from tests on site, and the results from laboratory tests. The condition shall be documented by description of visual survey, sketches, drawings, photos and test results.

Step 3: Evaluation

Based on the registered condition and possible defects, evaluation and verification shall be carried out. This includes the evaluation of the concrete structure regarding dimensions, geometry, materials, structural capacity, maintenance and repair options, and their associated costs.

In order to classify the condition of structures or structural parts in a uniform way, the concept of condition levels is introduced. It is defined as the expression of the condition of an object compared to a reference level, normally the original state of the object. Structure condition is divided into six condition levels defined as:

Condition level 0: No symptoms of deterioration.
Condition level 1: Minor symptoms of deterioration.
Condition level 2: Moderate symptoms of deterioration.
Condition level 3: Severe symptoms of deterioration, including failure and loss of serviceability.
Condition level 4: Potential hazardous.
Condition level 5: Unsafe.

In order to classify the consequences of the observed condition for a structure or a structural part in a uniform way, the concept of consequence levels is introduced. It is defined as the expression of the seriousness of the consequences of an object related to a defined reference level. The evaluation of the consequences of a condition level is important for the evaluation of repair actions. The decision of a consequence level is normally based on the assumption that no repair or maintenance is done within a certain time. Types of consequences to be evaluated are safety, cost, esthetics, health and environment. Five consequence levels are defined:

Consequence level 0:	No consequences.
Consequence level 1:	Small consequences.
Consequence level 2:	Medium consequences.
Consequence level 3:	Large consequences.
Consequence level 4:	Potentially hazardous or unsafe.

Alternate repair methods, as well as the possibility of using the "do nothing approach", and alternate methods of strengthening (if needed) should be evaluated based on comparative cost estimates, schedules, and relative levels of interference with the operations. A recommendation for the selected method or methods should be made for the owner's approval.

Step 4: Report

A report shall be produced for all assessment levels. The results from a lower assessment level may in some situations be included in the report after the following assessment level. The report shall include at least the following chapters:

1. Summary, basically an abstract of the report.
2. Introduction, including scope of investigation.
3. Original information.
4. Registration of observations.
5. Evaluation and verification.
6. Conclusions.
7. Recommendations.
8. A rough cost estimate (opinion of probable cost).
9. Possible annexes giving details (if necessary).

2.4.2.6 SAMCO "Guidelines for Assessment of Existing Structures"

SAMCO (Structural Assessment, Monitoring and Control Network) is a European network that constitutes a reference for industries, consultants and other organizations interested in the transfer of knowledge and technology in the field of assessment, monitoring and control of structures [12]. SAMCO gives descriptions of various assessment methods for existing structures with varying sophistication and effort. The assessment procedures are classified into two categories: qualitative assessment and quantitative assessment. As shown in Fig. 2.5 six levels of assessment are established:

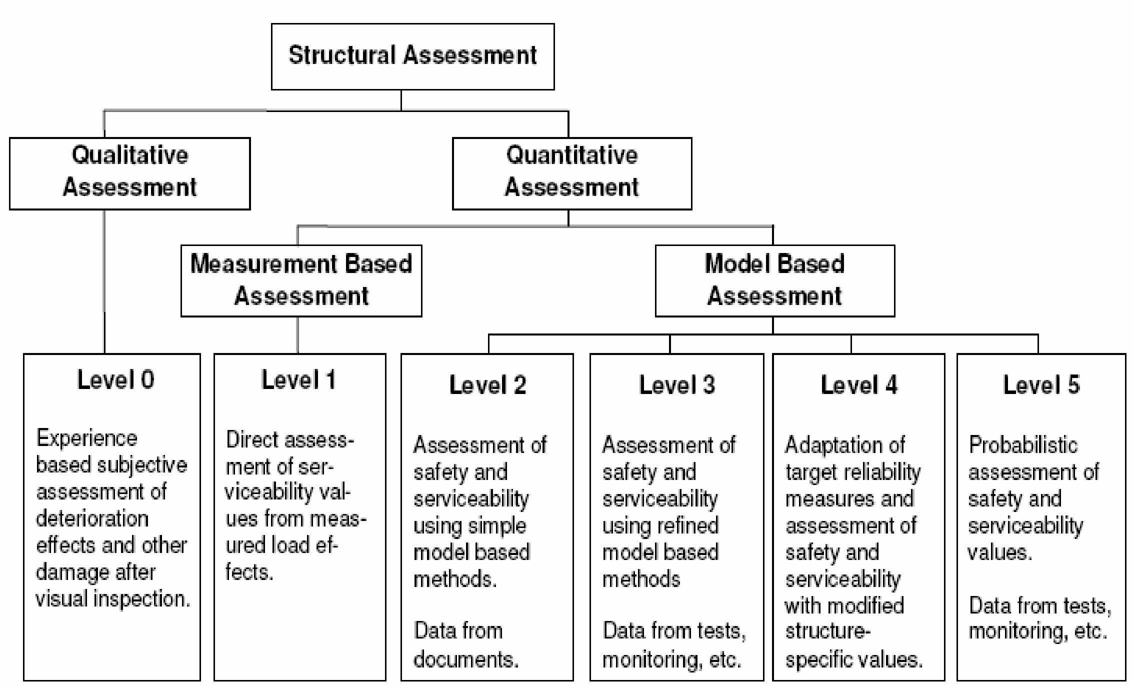


Fig. 2.5: SAMCO Assessment Methodology [12].

Level 0: Non-formal qualitative assessment

Assessment, based on experience of the engineer, is mostly used for a pre-evaluation of the structure. One is able to evaluate visual deterioration effects like corrosion of steel members or visual signs of damage (cracks, spalling, etc.).

Level 1: Measurement based determination of load effect

Assessment of serviceability is made by measurement of performance values and comparison with threshold values. There is no structural analysis carried out.

Level 2: Partial factor method, based on document review

Assessment of load-carrying capacity and serviceability is performed using information from design, construction and inspection documentation. Structural analysis is generally carried out using simple methods. Safety and serviceability verification is based on partial factors.

Level 3: Partial factor method, based on supplementary investigation

This level includes the assessment of load-carrying capacity and serviceability using information from site specific detailed non-destructive investigations. Structural analysis is carried out using refined methods and detailed models. Safety and serviceability verification is based on partial factors.

Level 4: Modified target reliability, modification of partial factors

This involves the verification of the load–carrying capacity with site-specific modified partial safety factors. Structural properties as well as external circumstances can influence the safety measure. Practically, modifying of partial factors is carried out for groups of structures with similar structural behavior or load influences.

Level 5: Full probabilistic assessment

A full probabilistic assessment is considered, taking into account all basic variables with their statistical properties. Structural reliability analysis is used directly and instead of partial factors. Uncertainties are modeled probabilistically.

It is recommended to start the assessment with simple but conservative low level and, in case the assessment failed, move on with more refined upper levels. There may be cases were a mixture of methods with low and high complexity is advisable.

2.5 ASSESSMENT PRACTICE IN GAZA STRIP

Several local institutions and consulting firms in the Gaza Strip undertake studies of assessment and evaluation of the faults in existing structures. Until now, there is no national standard in Palestine concerned in assessment and evaluations of existing structures with regard to their structural strength, safety, and serviceability. A detailed investigation into local assessment practice is found in chapter 4. The local practice of assessment involves some or all of the following steps:

1. Site visits and visual inspection.
2. Measurements and surveying works.
3. Assessment of soil bearing capacity.
4. On site and/or laboratory testing of concrete and other building materials.
5. Evaluation by experience and/or by structural analysis.
6. Assessment report.

2.6 CONCLUDED REMARKS

Rehabilitation of deteriorated concrete structures is an art as well as a science. The rehabilitation engineer must have the ability and tools to select any of the several rehabilitation techniques to fix the condition of the structure. The preceding assessment methods are planned approaches to investigate the condition of concrete structures or individual elements, diagnose the damage, and give the optimum solution.

Assessment of existing structures is needed for a variety of reasons. They can be handled in order to investigate the structural adequacy or suitability to accommodate intended changes in use, changes in code provisions, regulations, or increase of loads. Also it can be needed to evaluate the condition of structures susceptible to deteriorations caused by various environmental and chemical attacks, evaluation of damaged locations after extreme loading events, or even just after construction due to a range of construction errors and materials deficiencies.

The assessment can be carried out with methods of varying sophistication and effort. The objectives are to analyze the current condition of the structure and to predict the future performance with a maximum accuracy and a minimum effort [12]. While some assessment methods give general recommendations and simple qualitative measures with little details (e.g. ACI 364.1, ACI 201.1), others give more detailed procedures (e.g. ACI-473, CONTECVET and SAMCO). Moreover, European standards and manuals are now available giving comprehensive management systems for maintenance and rehabilitation of existing structures.

All the assessment methods persist on that the assessment effort made should not go deep into details more than the building condition requires. For this reason they all start by a site visit and simplified techniques for condition assessment of structures followed by more and more complicated testing methods to appraise the structural condition to an acceptable level of accuracy. The assessment steps involved in any assessment method are required to:

1- Give a description of the current condition of the structure.
2- Identify the defects.
3- Identify the prime cause or causes of defects.

4- Analyze the situation and decide the appropriate intervention action to be followed.
5- Make rehabilitation design, selection of materials, and repair method.

All of this should be carried out in a way proportional to the structure itself, the owner's requirements, and approved budgets.

For small projects such as the case of defects in private buildings where minor or moderate damages could be encountered, qualitative assessment approaches may be reasonable. In these approaches the assessment is based on various levels of assessment comprising site visits, visual inspection, on-site or laboratory testing, and evaluation by experience and/or structural analysis.

On the other hand where large projects are under consideration, both qualitative and quantitative assessment approaches could be used. Also in this case various levels of assessment are in use depending on the type and extent of deteriorations, the feasibility of rehabilitation works, and budget constraints. With this regard the European approaches (e.g. CONTECVET, and SAMCO) are typical examples of such methods of assessment.

In Europe, rehabilitation manuals and standards are available nowadays (e.g. REHABCON, and EN-1504). The concentration of these documents is made on management systems that optimize the repair of deteriorated or defected large heritage of structures on the basis of priority concepts concerning intervention actions. Several systems for management are described in literature with ranking methods enabling the optimization of repair options and materials. **Indeed it seems that the efforts associated with such methods are not proportional to the expected cases of damage in Gaza Strip.**

The assessment practice in Gaza Strip follows to some extent the qualitative approach of assessment where simple steps with minimal assessment efforts and few testing are generally in use. Usually a team of engineers performs a site visit in which possible data are collected and a survey of defects is made. The next step is to decide if additional testing is needed or not, then evaluation of the structure condition is made. At the end recommendations of intervention actions are given in the assessment report. The assessment practice in Gaza Strip is very simplified to the extent that it becomes unsatisfactory in many cases where the following shortcomings can be pointed out:

1- Some cases are assessed based on team experience only while the situation requires more in depth investigations.

2- Scientific methods for identification and description of damages such as their causes, types, extent, etc. are not followed in many cases.

3- Little efforts are exerted in local assessment practice regarding the details of repair and rehabilitation methods to be used in correcting the encountered problems.

4- No testing or limited concrete testing is used in local assessment practice. Although accurate assessments usually need various types of tests for proper identification of damages in existing structures.

For these reasons, the local assessment practice needs to be examined carefully and modified to keep pace with global development in the field of assessment and evaluation of existing structures.

CHAPTER 3: DEFECTS IN CONCRETE STRUCTURES AND REHABILITATION TECHNIQUES

3.1 INTRODUCTION

Concrete structures exhibit a variety of defects during their life time from the design stage to service stage. These defects vary from very simple and negligible defects which occur almost in all structures, to very severe and destructive deteriorations that may cause excessive damages to the structure or even its collapse. The assessment and repair of defects in existing structures require good knowledge and experience to identify the defects, their causes and how to prevent and repair them.

The working life of the structure may be reduced or extensive maintenance may be required as a result of deterioration of materials, usually steel subject to corrosion attack or concrete subject to aggressive chemicals. Evidence of this type of damage may appear after 15 or 20 years and is strongly environment dependent [26].

Case studies regarding defects occurring in existing buildings in Gaza Strip have shown that Gaza Strip environmental conditions play an important role in propagation of some types of defects such as deterioration of concrete and corrosion of steel reinforcement. Also some defects were associated with design errors, construction errors, and poor quality concrete. Fire as an accidental event caused many defects in a considerable number of cases as well, in addition to many damages that were caused by Israeli military attacks. These findings made it essential to review such defects in literature and make efforts in gathering information regarding the most common defect types occurring in concrete structures illustrated with photographs where possible. This is to give the assessment engineer a tool appropriate to easily identify the defects, detect their causes, and report the condition of the structure in a scientific and a standard way.

3.2 CAUSES OF DAMAGES IN EXISTING STRUCTURES

Damages in existing structures continue to be of a growing concern. Accurate information on the condition of concrete in existing structures is critical to evaluate its safety and serviceability. This information is required by decision makers to determine if repair or replacement is necessary and to select optimum repair techniques where conditions require [27]. A basic understanding of the causes of concrete deficiencies is essential to perform meaningful evaluations and successful repairs. If the cause of a deficiency is understood, it is much more likely that an appropriate repair system will be selected, consequently, the repair will be successful and its maximum life will be obtained. Symptoms or observations of a deficiency must be differentiated from their actual causes. Only after the causes are known, rational decisions can be made concerning the selection of a proper repair system [9].

In most cases, the defects in existing structures can be traced to one or more of the following types:

1. Signs of poor quality in design and construction: such as wetting or dampness, leakage, structural or non-structural cracks, foundation settlements, etc.
2. Physical damage such as freeze-thaw action, cracking due to thermal movement, and shrinkage cracking.
3. Mechanical damage due to for example, impact, explosions, abrasion, etc.
4. Chemical damage such as carbonation, chloride contamination or ingress, and Alkali-silica reaction.

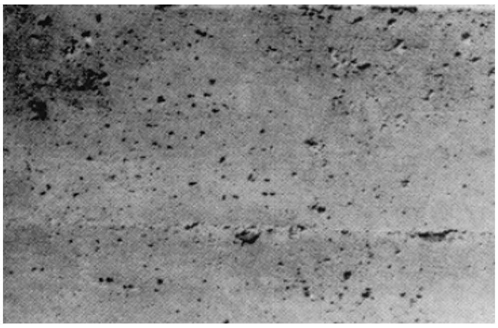
Progressive cases of damages and defects can arise and accelerate in certain environments and if the concrete has insufficient cover, or is porous [11].

Several ways can be followed to classify damages of defects. They can be classified according to their causes, types, or severity. The following section gives a classification of defects and damages in accordance with their causes.

3.2.1 Damages Caused By Construction and Design Errors

3.2.1.1 Damages Due To Construction Errors

When the concrete structure is newly constructed some types of damage attributable to unsatisfactory construction practice may occur. The damage may have an immediate effect on the structural integrity. Poor construction usually leads to reduced durability which manifests itself in later years. Also poor construction practices and neglect can cause defects that lead to the cracking and concrete deterioration [26]. Typical construction faults that may be found during a visual inspection include bug holes, evidence of cold joints, exposed reinforcing steel, honeycombing, irregular surfaces caused by improperly aligned forms, and a wide variety of surface defects and irregularities. These faults are typically the result of poor workmanship or the failure to follow accepted good practice [28]. Various types of construction faults are shown in Fig. 3.1.



Bugholes (www.usace.army.mil)

Honeycombing (Al-Nasser Hospital-Gaza)

Cold Joints (www.enhance-solutions.com)

Blistering (www.structuraldesigns.com.au)

Segregation (Al-Nasser Hospital-Gaza)

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

Fig. 3.1: Typical Construction Faults in Concrete.

3.2.1.2 Damages Due To Design Errors

The design errors can be broadly categorized into two types: inadequate structural design and poor design details as follows:

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 areas of high stress concentration. These problems can be prevented with a careful review of the design calculations and detailing [26].

b- Poor Design Details

Detailing is an important component of a structural design. Poor detailing may contribute to the deterioration of the concrete since missing details may lead to improper construction practice or materials deficiency in quality the matter that results in deteriorations and defects in concrete structures [26].

3.2.2 Damages in Concrete Due to Physical Causes

3.2.2.1 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 [29].

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

Fig. 3.2: Plastic Shrinkage Cracks.
(www.cement.org/tech/faq_cracking.asp**)**

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 form 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 [30].

b- Settlement Cracking

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 slump, and decreasing cover. The degree of settlement cracking may be intensified by insufficient vibration or by the use of leaking or highly flexible forms [30].

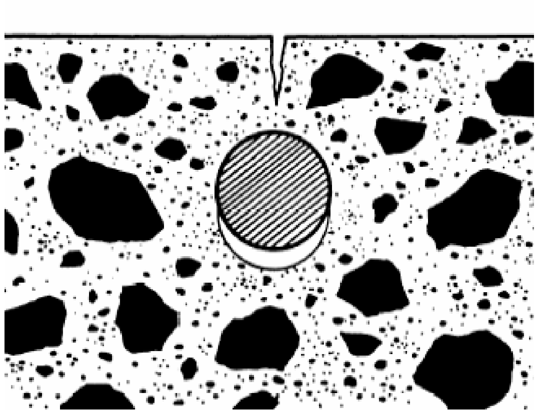


Fig. 3.3: Settlement Cracks.
(ACI 224.1- R93)

3.2.2.2 Damages in Concrete after Hardening

a- Drying Shrinkage Cracks

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.

Fig. 3.4: Craze Cracks.
(www.prairie.com)

When the tensile strength of concrete is exceeded, 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 [30].

Fig. 3.5: Drying Shrinkage Cracks due to Improper Joint Spacing.
(ACI 302.1- R04, www.portcement.org)

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 that shown in Fig. 3.5

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 columns, piers, beams, and footings, 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 [30].

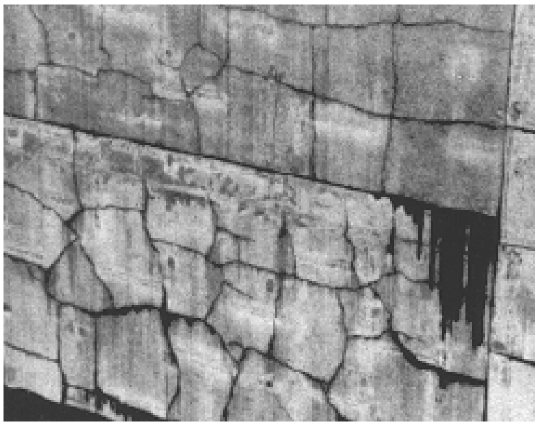


Fig. 3.6: Pattern Cracking Caused by Restrained Volume Change.
(www.usace.army.mil)

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 fire accelerates. The extent of damage depends on the temperature reached, loading conditions under fire, and characteristics of the concrete, which includes the quality of concrete and type of aggregates used [31]. Typical fire damage is shown in Fig.3.7.

Fig. 3.7: Typical Fire Damages.
(IUG Library Building-March, 2008)

c- Weathering Cracks

The weathering processes that can cause cracking include:

1. Freezing and thawing.
2. Wetting and drying.
3. Heating and cooling.

Damage 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 in 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 [30].

3.2.3 Deterioration of Concrete Due to 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 [8]. The main causes of deterioration of concrete structures are briefly explained as follows[31]:

3.2.3.1 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. The time before repair, often referred to as the service life of the reinforced concrete element, is determined by the total time of these two stages [31].

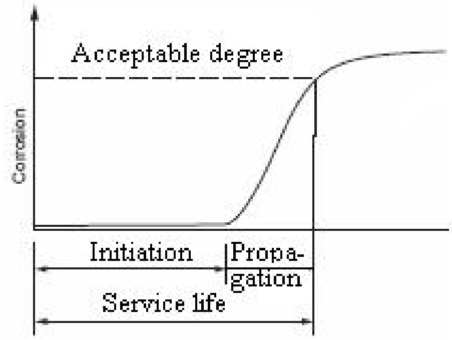
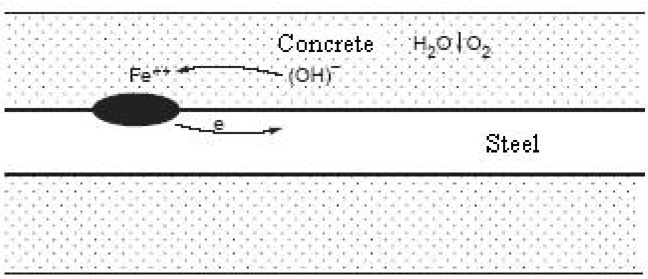


Fig. 3.8: Schematic Diagram of Corrosion Process of Steel in Concrete [31].

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.



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

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

Fig. 3.9: Schematic Representation of Electro-Chemical Reaction [31].

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 [31].

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 [8].

3.2.3.2 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 [31].

3.2.3.3 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 [31].

3.2.3.4 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 [31].

3.2.3.5 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 [31].

3.2.3.6 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 [31].

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.

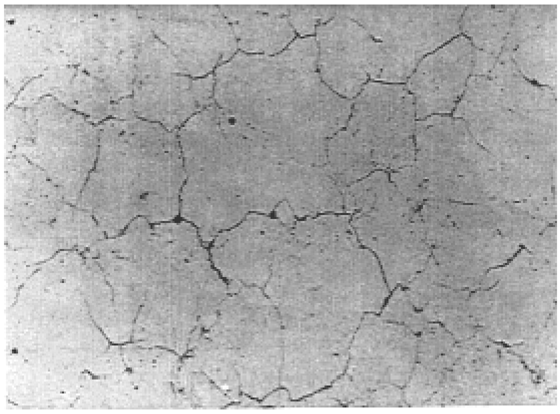


Fig. 3.10: Craze Cracks (Map Cracking).
(ACI 201.1R-92)

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 [32].

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 [32].

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 [32].

3.3.4 Efflorescence

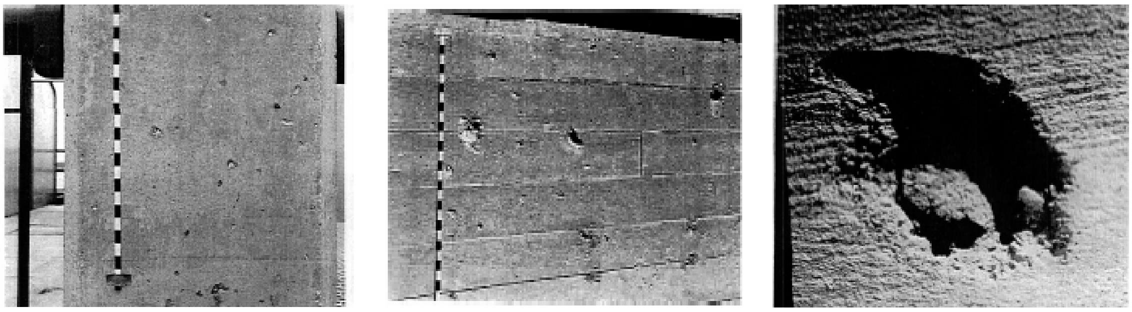
Efflorescence can be considered a type of discoloration. It is a deposit, usually white in color that occasionally develops on the surface of concrete, often just after a structure is completed. Efflorescence is usually harmless. In rare cases, excessive efflorescence deposits can occur within the surface 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 [33].

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

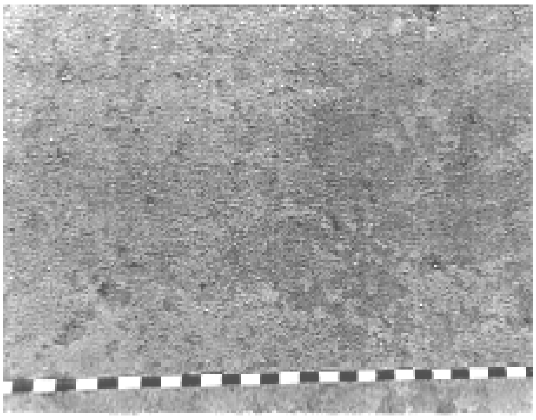
Fig. 3.12: Popouts. (ACI 201.1R-92)

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.

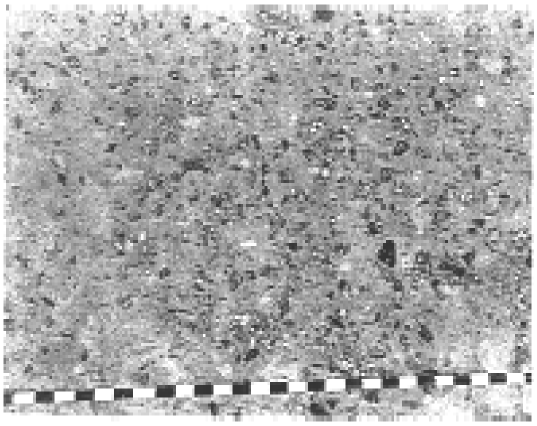
Popouts are considered a cosmetic detraction and generally do not affect the service life of the concrete [29].

3.3.6 Scaling

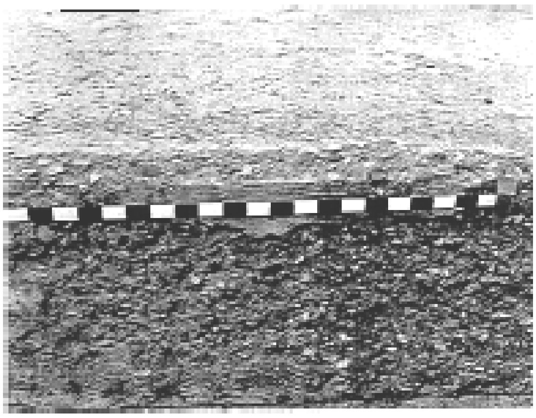
Scaling is a local flaking or peeling away of the near-surface portion of hardened concrete or mortar. It may be light scaling (loss of surface mortar without exposure of coarse aggregate), medium scaling (loss of surface mortar 5 to 10 mm in depth and exposure of coarse aggregate), severe scaling (loss 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 [21].



Light Scaling



Medium Scaling



Severe Scaling

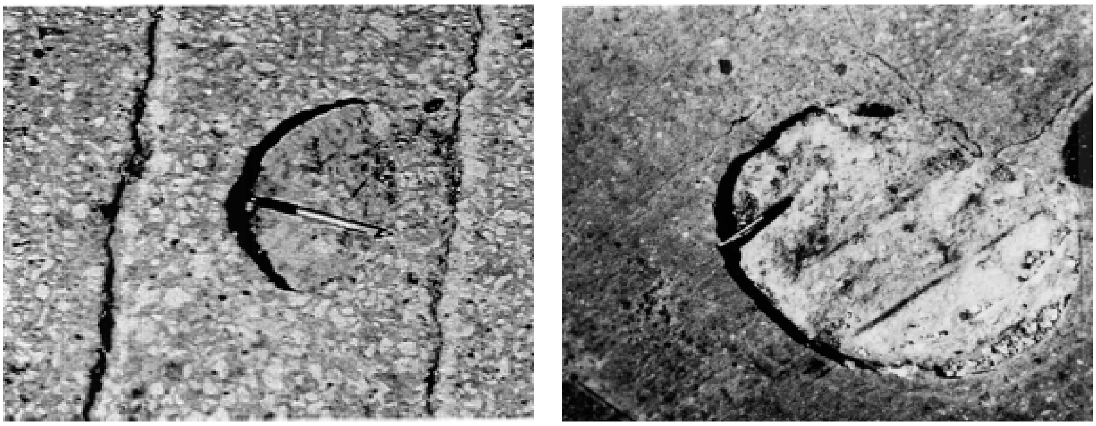
Very Severe Scaling

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 [21,33].

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 [32].



(a) Small Spall **(b) Large Spall**

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

3.4 REHABILITATION TECHNIQUES

3.4.1 Introduction

Rehabilitation of existing structures is the process of repairing or modifying a structure to a desired useful condition [4]. It involves improvement of existing structures physical condition through treatment (repair, restoration, protection, and /or strengthening) after defects are encountered to restore or enhance one property or more such as durability, structural strength, function, or appearance, and thus bringing degradation under control to enable the structure to continue serving its intended purpose. This can be either repairing to bring concrete back to a state similar to the original, or using methods to arrest deterioration processes to enable ongoing service [5].

Once the assessment of a damaged structure has been completed and the decision of repair has been taken, the most appropriate repair technique or combination of techniques has to be selected through available options that can be used. Several rehabilitation principles and methods for repair are available in literature concerning repair of structural defects and protection of the structure from further deterioration. Principles for repair are used as basic objectives to be fulfilled by repair methods [19]. Several principles for repair were adopted by different institutions world wide, for example, by the European standards. The main principles for a remedy of a problem are:

1. Protection against ingress of adverse agents.
2. Moisture control.
3. Concrete restoration.

4. Structural strengthening.

For each principle several repair methods can be used. The selection of a repair method depends on several factors such as:

1. Type and extent of distress.
2. Location of distress.
3. Environmental exposure.
4. Appearance.
5. Cost.
6. Availability of repair materials.
7. Availability of skilled personnel and equipments [8].

The last two factors are of high importance at local level because of the political situation in Gaza Strip and the lack of practical experience.

3.4.2 Materials for Repair

A wide range of repair materials for concrete is available in the world at different costs and performance characteristics. Their application range covers:

1. Materials for surface preparation.
2. Chemicals for rust removal from corroded reinforcement.
3. Passivators for reinforcement protection.
4. Bonding agents.
5. Structural repair materials.
6. Non-structural repair materials.
7. Injection grouts.
8. Joint sealants.
9. Surface coatings for protection of reinforced concrete.

These products are generally pre-proportioned and in pre-weighed packs together with accompanying instructions regarding mixing procedure, dosage and application procedure etc. [8]

Repair materials may be classified into three general groups: Cement based, Polymer based, and Polymer modified materials [34].

Cement based materials are those generally prepackaged materials requiring only the addition of water. Their physical properties are very similar to those of concrete and they achieve strengths to or greater than the concrete being repaired. Also thermal coefficients of expansion are nearly identical to that of concrete. The main disadvantage of most cementitious products is that they don't develop adequate bond strength.

Polymer-based materials include epoxies, polyesters, and acrylics. They are most commonly used where chemical resistance is required. Most of the polymer-based repair materials achieve high strength and good bond to a properly prepared and dry substrate.

There are some disadvantages to these materials:

1. They are generally more difficult to work with as compared to cement based materials.
2. They exhibit varying degrees of toxicity and flammability. So they should be used with caution.
3. Proportioning the components and mixing are critical to proper curing.

Polymer-modified materials are also polymer based with modifications or improvements including increased bond strength, reduced permeability, increased resistance to freezing and thawing, and increased flexural strength. The specific property improvement to the modified mortar and concrete varied with the type of latex used.

Applications of these materials include floor leveling, concrete patching, and bridge deck overlays.

In addition, all of the polymer-based repair materials are more expensive than cement based materials. Regardless of the type of repair material, an adequate inventory should be kept in stock. Any repair material chosen to be kept in stock must have an adequate shelf life. These materials may remain in inventory for months and must retain their efficacy. A shelf life of a minimum of 6 months is highly recommended [34].

3.4.3 Factors Affecting the Selecting of Repair Materials

When selecting a repair material, several properties could be considered. Some important properties in considering a concrete repair material are:

1- Length change.
2- Bond strength.
3- Compressive strength.
4- Consistency.
5- Working time.
6- Thermal coefficient of expansion.
7- Durability [34].

3.4.4 Repair Techniques

Several repair methods and techniques are available nowadays. They cover all aspects of damages occurring in existing concrete structures. Although several classifications of these techniques can be found in literature, the following classification was selected for repair methods according to their physical function or method of action [19]. This selection is made to match with the previously described principles of repair.

3.4.4.1 Surface treatments

Surface treatments are used to maintain old structures and protect them against different deterioration processes or reduce the deterioration rate. They can increase the length of the initiation period preceding the degradation by limiting transport of water, chloride, sulfate, acids or some other aggressive compounds. On concrete structures where degradation has started the deterioration rate might be reduced, and then consequently the service life can be extended, by the use of surface treatments.

Surface protective treatments can be classified into three types:

1- Hydrophobic impregnation.
2- Impregnation.
3- Coating.

Hydrophobic impregnation produces a water-repellent surface; impregnation produces a discontinuous thin film (usually 10µm – 100µm) that partly fills the capillaries, and coatings produce a continuous layer (typical thickness 0.1mm – 5.0mm) on the surface of the concrete [19].

3.4.4.2 Injection and sealing of cracks

Cracks are normal in reinforced concrete structures. However, they can have a negative influence on the durability and integrity of the structure and in many cases action has to be taken. Before taking any action however, it is important to determine whether injection/sealing is an appropriate remedial measure. The cause of the cracking must be identified, as treatment methods will vary depending on whether the cracks are dormant or live. The moisture conditions within the concrete must be known. In some cases, injection or sealing of cracks is not appropriate. Injection should not be used where the reinforcement is corroding or where the cracks are caused by corrosion.

Crack injection, although often used in conjunction with strengthening, is not a strengthening method in itself. It is used to repair cracks in reinforced concrete components to avoid progressive damage, maintain integrity of the concrete and improve durability. While crack injection improves the tensile capacity of the concrete locally, the overall stiffness of an injected beam is only marginally modified, as new cracks can develop in the un-repaired concrete.

There are two main methods to treat cracks [19]:

a. Injection: an internal treatment used to fill most of the cracks and voids and thus seal the cracks.
b. Surface sealing: an external used to protect the concrete or the reinforcement from ingress of aggressive materials. Sealing can be divided into two groups:
    i. Membranes applied either as liquids or preformed (bonded or un-bonded) sheets.
    ii. A suitable sized groove is made and filled with an appropriate sealant.

Injection is usually made with hydraulic binders, polymer binders or gels injected through holes drilled into the cracks. It can be carried out through a half pipe attached to the concrete surface along cracks.

Surface sealing with grooves is usually used for live cracks. The width of the groove is dimensioned in such a way that the total movement will not exceed about 25% of the width.

The depth of the groove is dependant on the sealant, which can be some type of mastics, or thermoplastics. Membranes can be used to seal just the cracks or the whole surface. At live cracks an area along the crack is usually un-bonded [19].

3.4.4.3 Patching

Patching is a repair technique for concrete structures which consists of replacing the lost, unsound or contaminated concrete with a material that can be new concrete, a repair mortar, a grout, etc. The objective of patching is to restore the esthetical and geometric properties of the structure in order to maintain its structural safety and increase its durability.

If the reinforcement is corroded, or corrosion is likely to occur as a result of a thin, non-existing or contaminated cover, the procedure of patching also includes cleaning the reinforcement rust and protecting it from further corrosion before the concrete cover is restored.

Patching consists of the following stages [19]:

a. Identification of unsound/contaminated concrete
b. Removal of unsound concrete
c. Cleaning of concrete substrate and reinforcements
d. Application of the repair material
e. Surface treatment of the concrete substrate in order to increase bond strength

Patching is a very cost effective repair method, fast and very effective if it is well executed. On the other side, if execution is not right, patch repairs will be of no use for the structure. It is essential for the sake of the repair that the surface of the concrete substrate is completely cleaned, it is treated to improve bond strength, and the repair material is compatible with the old concrete.

Patching is an effective method for repair of local areas where there is no necessity to increase the strength of the structure. Patching is usually carried out to repair damage which does not compromise the structural strength. If the deterioration has affected strength, there are other methods which may be more suitable for the repair. Patching is also used to repair damages that may affect the appearance of the structure [19].

3.4.4.4 Strengthening with reinforced concrete

a- Introduction

Strengthening with reinforced concrete can be used on structures affected by corrosion, salt-frost attack, mechanical wear, acid attack, alkali silica reaction (surface attack), sea water attack, leaching by pure or natural water, accidental load, overload, and structural load.

Strengthening with reinforced concrete can be divided into two different types [19]:

a. Bonding of hardened concrete to hardened concrete, typically associated with the use of precast units in repair and strengthening.
b. Casting of fresh concrete to hardened concrete using an adhesive bonded joint forming a part of the structure requiring composite action.

The structural repair with reinforced concrete consists normally of the following actions [19]:

a. Removing contaminated, cracked, or defective concrete.
b. Removing and replacing corroded reinforcement.
c. Adding protection to the reinforcement.
d. Casting and/or adding new reinforced concrete section for strengthening of the structure.

b- General Considerations

It is important to ensure compatibility with the parent concrete, as well as full composite action. Pre-preparation is crucial, to ensure bond with the substrate and the reinforcing bars. Good workmanship is paramount for all application methods, which may be used [19].

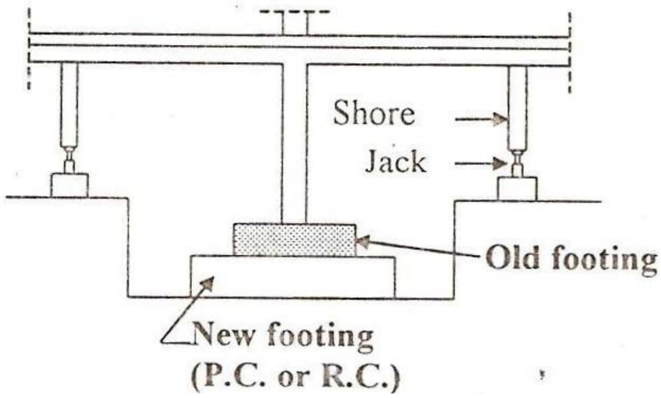
c- Strengthening Techniques for RC Elements [3]

There are many common methods for strengthening of various reinforced concrete elements in use worldwide. Their design is dependant on the type of the structural deficiency and the needed sectional capacity after strengthening. Also the design considerations are different from those for new constructions.

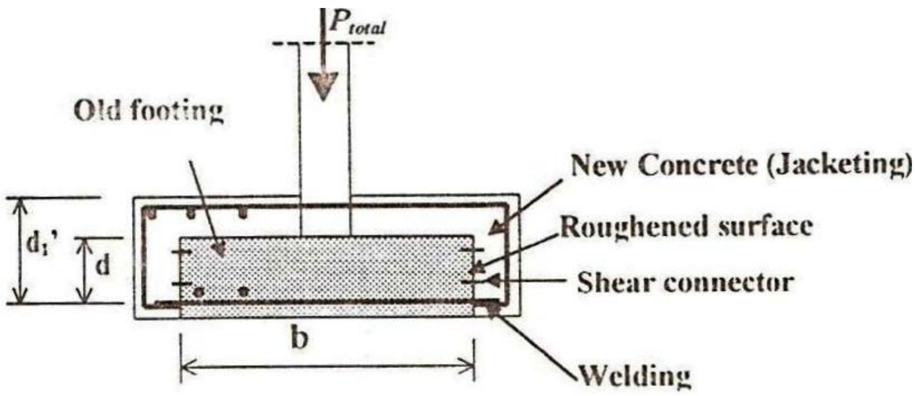
1- Strengthening of Shallow Foundations

Several methods for strengthening of shallow foundations could be used including:

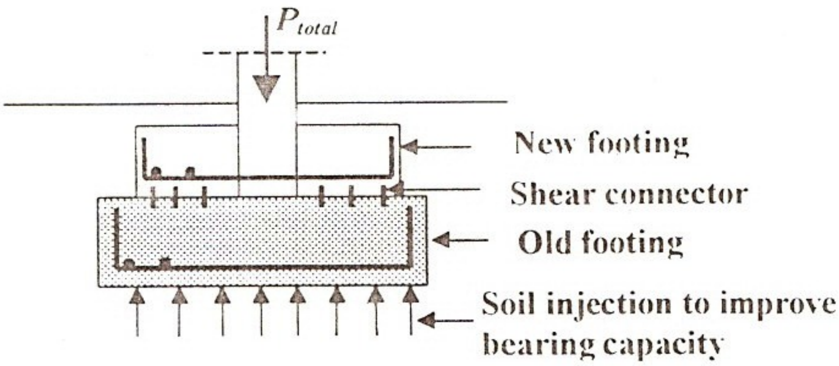
i. Increasing of bearing areas under spread footings thus increasing the resistance against wide-beam, two-way shear and bending moments as shown in Fig. 3.15.



(a) New footing underneath



(b) Jacketing on top



(c) New footing on top

Fig. 3.15: Increasing Bearing Areas under Spread Footings [3].

ii. Connecting spread footings to work as a combined footing or a mat foundation as illustrated in Fig. 3.16.

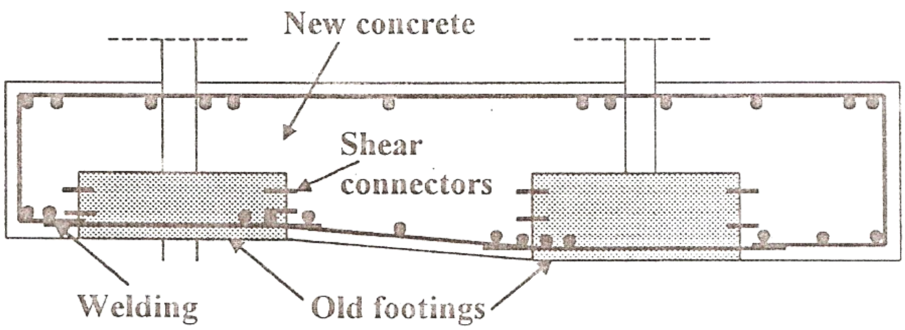


Fig. 3.16: Connecting Spread Footings [3].

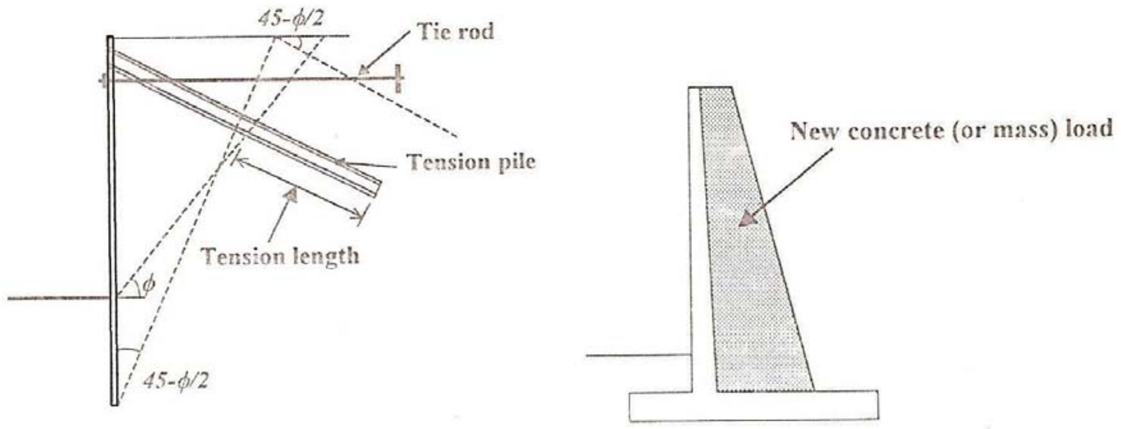
iii. Increasing the depth of a mat foundation by a reinforced concrete overlay thus modifying the flexure and shear resistance of the foundation.

2- Strengthening of Retaining Walls

The strengthening or retaining walls comprises the following:

i. Increasing the retaining wall cross-section.

ii. Increasing resistance to overturning forces by adding tie rods or tension piles as shown in Fig. 3.17 (a), or converting the wall to a gravity retaining wall as shown in Fig. 3.17 (b).



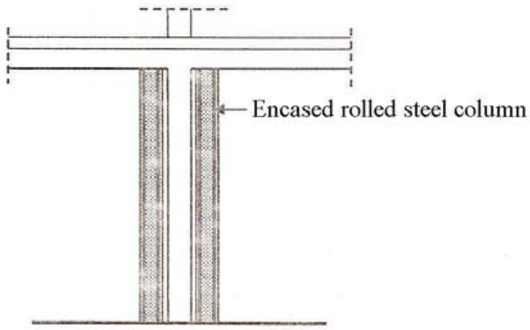
(a) Adding a tie rod or a tension pile **(b) Conversion to a gravity retaining wall**

Fig. 3.17: Increasing Resistance of Retaining Walls to Overturning [3].

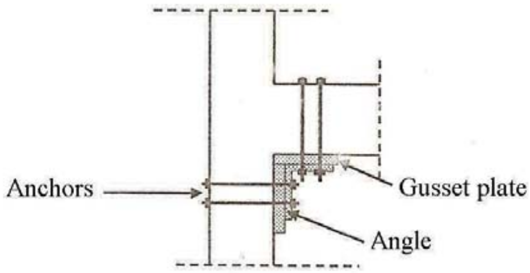
3- Strengthening of Walls and Columns

Several methods for strengthening walls and columns can be used such as [3]:

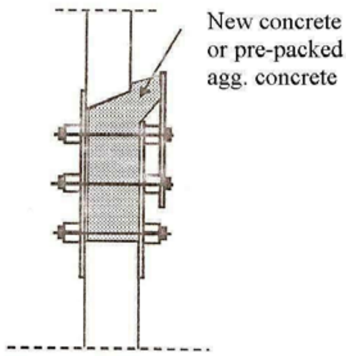
i. Permanent propping using encased rolled steel columns to increase the load carrying capacity as shown in Fig. 3.18 (a).
ii. Increasing flexural capacity by use of moment resisting connections as in Fig. 3.18 (b).
iii. Replacement of a damaged or defected part of columns or walls as shown in Fig. 3.18 (c).
iv. Strengthening by the use of jacketing techniques as illustrated in Fig. 3.18 (d).



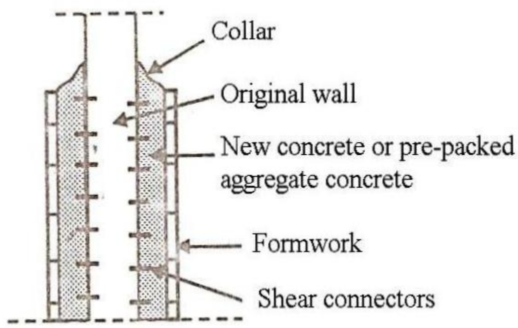
(a) Permanent propping



(b) Moment resisting connection



(c) Replacement of part of column or wall



(d) Jacketing of walls

Fig. 3.18: Strengthening of Walls and Columns [3].

Fig. 3.19 illustrates reinforcement details for column jacketing according to the number of faces of encasement.

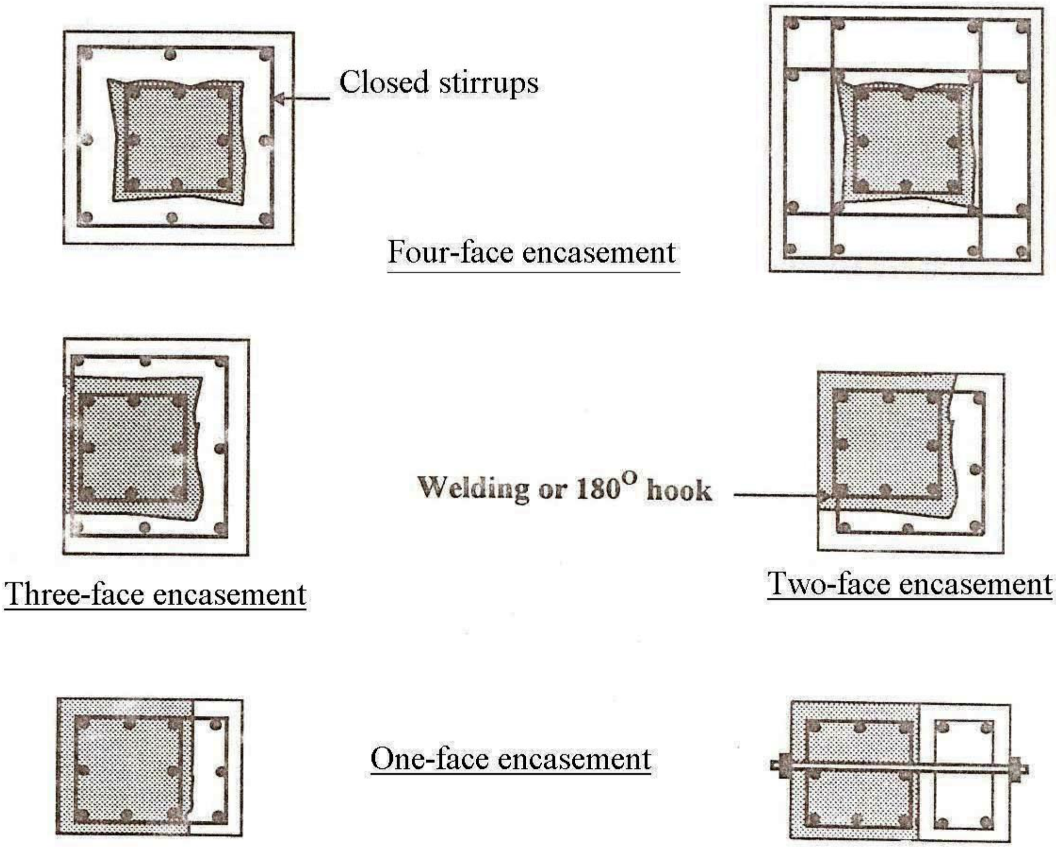


Fig. 3.19: Jacketing Reinforcement Details [3].

4- Strengthening of Beams

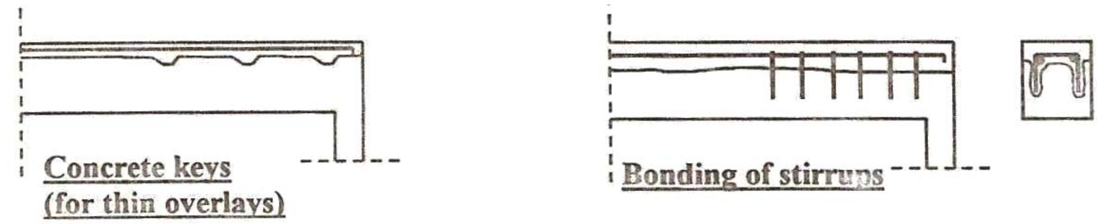
Beams can be strengthened using the following methods:

i. Adding a compression concrete overlay and resisting of laminar shear as shown in Fig. 3.20 (a).

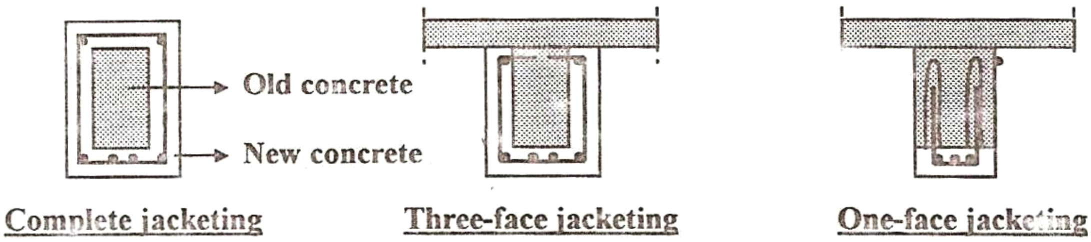
ii. Increasing the depth and/or the width of beams by jacketing as illustrated in Fig. 3.20 (b).

iii. Increasing transverse reinforcement to modify shear and torsion resistance of beams as in Fig. 3.20 (c).

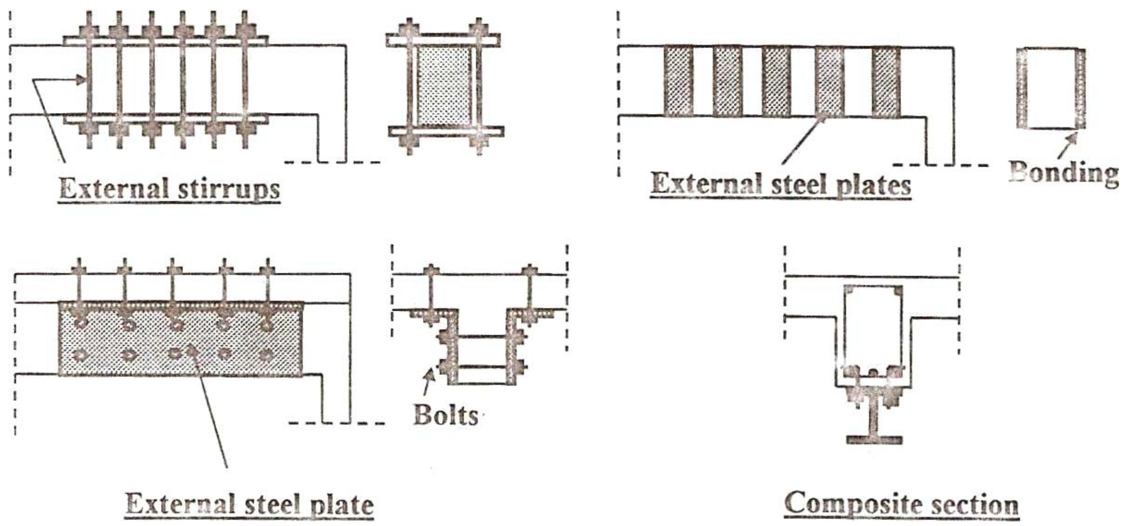
iv. Increasing shear and flexural capacity of beams by span shortening using additional new concrete or steel columns as illustrated in Fig. 3.20 (d).



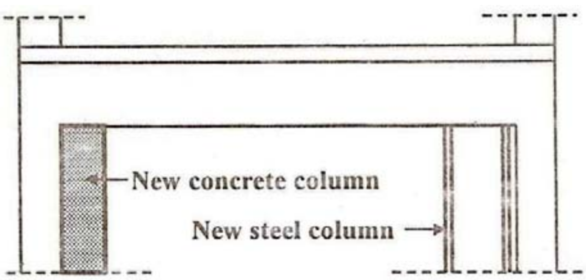
(a) Adding a compression concrete overlay and resisting of laminar shear



(b) Increasing depth and/or width (Jacketing of beams)



(c) Increasing transverse reinforcement



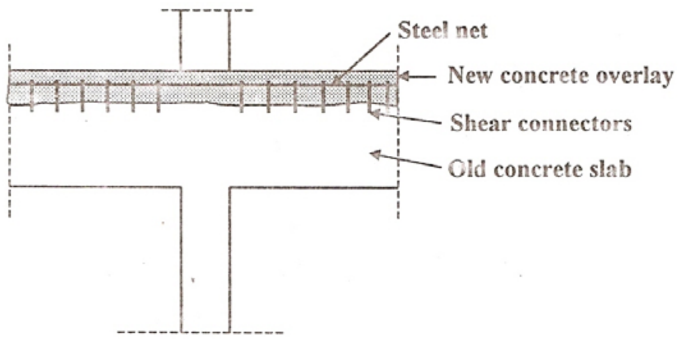
(d) Span shortening

Fig. 3.20: Strengthening of Beams [3].

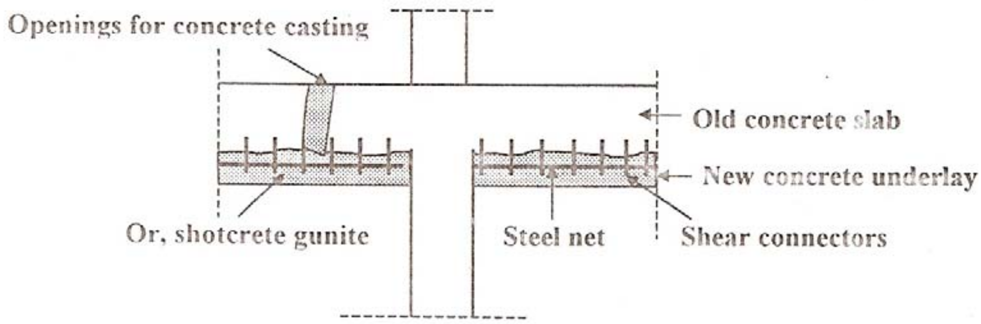
5- Strengthening of Slabs

Slabs can be strengthened by the following techniques:

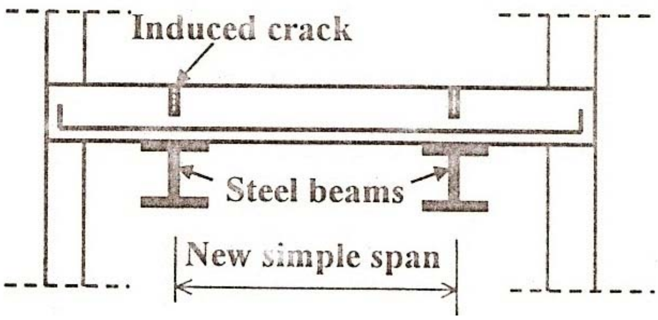
i. Strengthening using concrete overlays as shown in Fig. 3.21 (a)
ii. Strengthening using concrete under-lays as in Fig. 3.21 (b).
iii. Span shortening using steel beams such as in Fig. 3.21 (c).



(a) Concrete overlays



(b) Concrete under-lays



(c) Span shortening

Fig. 3.21: Strengthening of slabs [3].

3.4.4.5 *Other methods for strengthening*

Several other methods and techniques are used worldwide for strengthening of reinforced concrete structures. Among these methods the following can be listed:

i. Strengthening with carbon fibers.
ii. Strengthening using externally bonded steel plates.
iii. Strengthening using external post-tensioning.

3.4.4.6 *Electrochemical techniques*

The electrochemical techniques used for stopping corrosion in concrete structures are [19]:

i. Cathodic Protection.
ii. Chloride Extraction.
iii. Re-alkalization.

All electrochemical maintenance methods have principles and practical details in common. The main differences are the amount of current flowing through the concrete and the duration of the treatment. The general set-up that is valid for all electrochemical methods is that by means of an external conductor, called the anode, a direct current is flowing through the concrete to the reinforcement which thereby is made to act as the cathode in an electrochemical cell. The final result of the current flow is to mitigate or stop the corrosion by depassivation of the rebars due to polarization of the reinforcement to a more negative potential, or by removing the aggressive ions (chloride) from the pores of the concrete or by reinstating the alkalinity of the pore solution [19].

3.5 CONCLUDED REMARKS

Various types of damages occurring in concrete structures that could be encountered in Gaza Strip and their relevant rehabilitation techniques have bean reviewed to facilitate the identification of damages in the existing buildings in Gaza Strip, detect their causes, report the condition of the structure in a unified scientific way and select the appropriate rehabilitation technique.

Gaza Strip environment and prevailing conditions were considered while gathering information about damage types and rehabilitation techniques. For example some damages such as those resulting from aggregate silica reactions or frost attack were not reviewed since such damages were not reported in cases in Gaza Strip. Also the rehabilitation techniques reviewed have been selected such that they could be cheap, available, and suitable for the damages in Gaza Strip regarding their types, extents, and quantities.

This has played an important role in the development of the proposed assessment approach that was intended to suit the prevailing conditions in Gaza Strip. Emphasis has been made on the cause, type, and extent of damage that determine the assessment route to be followed.

CHAPTER 4: CASE STUDIES SURVEY

4.1 INTRODUCTION

The aim of this survey is to study various aspects of rehabilitation of existing reinforced concrete buildings in Gaza Strip. This will enable the development of an assessment method suitable for use in Gaza Strip and to propose general rehabilitation procedures for deteriorations or defects encountered. For this purpose assessment reports of cases undergone by local institutions have been surveyed in order to:

1- Classify the causes and types of structural faults, damages, and deteriorations that occur in existing buildings in Gaza Strip subjected to normal conditions.
2- Identify the assessment practice and evaluation procedures used.
3- Find out the rehabilitation techniques used for repair.
4- Identify strong and weak points in current practice.

The typical process of assessment practice in Gaza strip is summarized in Fig.4.1 as follows:

1- In case of a problem, the owner of a building or his representative asks the institution or the consulting firm to assess the problems in his building.

2- The institution or firm nominates a team of specialists normally consisting of two or more engineers to respond to the owner's request.

3- In most of the cases the team visits the building, makes the assessment (with simple, moderate, or detailed procedures), and evaluates the findings.

4- Finally an assessment report is submitted to the owner or his representative.

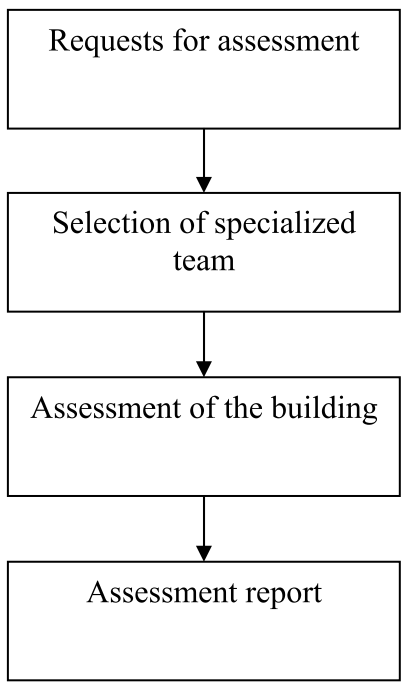


Fig. 4.1: Process of Assessment Practice in Gaza Strip.

4.2 BACKGROUND INFORMATION

The Gaza Strip is a coastal area located in the Middle East and consists of an area approximately 360 km^2. It has a temperate climate, with mild winters, dry and warm to hot summers. The terrain is flat or rolling, with dunes near the coast [35]. The map shown in Fig. 4.2 indicates that Gaza Strip has a 40 Km coastline onto the Mediterranean Sea. This location with the associated environmental conditions may have a considerable influence on the deterioration of existing concrete structures in Gaze Strip, especially steel corrosion.

Fig. 4.2: Gaza Strip Map.
(www.webscavengers.net)

In general, Gaza strip buildings are low rise reinforced concrete structures. Actually many buildings are of less than five floors, however, multistory buildings of heights ranging from 10 to 20 stories are present in Gaza Strip and stationed considerably close to the sea coast in many locations.

Some owners of buildings in Gaza Strip seek advice or consultancy regarding their buildings that may have some types of destructions or damages due to Israeli military actions, naturally occurring deteriorations, or construction errors. In Gaza Strip there are few local institutions and consulting firms having practical experience in assessment and evaluation of damages in existing structures. These include the Association of Engineers, the Ministry of Public Works and Housing, and the Islamic University-Gaza, in addition to some engineering consulting firms.

4.3 CASE STUDIES

In this research a survey of forty case studies for assessment of existing structures has been made. The survey included case studies performed by local institutions and consulting firms. It should be mentioned that these institutions and firms have conducted hundreds of cases on assessment and evaluation of defects and damages in existing buildings especially damages due to Israeli military actions. The survey concentrated on cases of naturally occurring deteriorations, construction errors, and damages due to accidental actions such as fire. Photocopies of assessment reports of the case studies have been collected from local institutions and firms. The cases were selected to cover Gaza Strip North, Middle, and South areas as possible. They are tabulated and briefly described in Table 4.1.

Table 4.1 List of Case Studies

Case No.	Date of Assessment	Building Location	Building Type	Cause of Assessment	Scope of Investigation
1	06-1997	Gaza	Stores and residential	Accidental	Structural assessment of a two floor building exposed to fire
2	11-1999	Gaza	Retaining wall	Concern about design and/or construction errors	Structural assessment of a retaining wall
3	01-2000	Gaza	Residential	Concern about design and/or construction errors	Structural assessment of RC slab recently poured
4	03-2000	Gaza	Public	need to add additional floor	Structural assessment of one floor building
5	04-2000	Gaza	Residential	Signs of deteriorations and/or defects	Assessment of plaster works
6	06-2000	Gaza	Residential	need of architectural modifications	Assessment of one floor building
7	06-2000	Jabalia	Residential	Accidental	Assessment of two floor building exposed to fire
8	07-2000	Jabalia	Residential	Signs of deteriorations and/or defects	Assessment of one floor building
9	08-2000	Beit Hanoun	Public	Concern about design and/or construction errors	Assessment of concrete strength of 2^{nd} slab of a mosque
10	09-2000	Gaza	Residential	Signs of deteriorations and/or defects	Structural assessment of a seven floor building
11	10-2000	Gaza	Residential	Concern about design and/or construction errors	Evaluation of G.F columns after pouring
12	10-2000	Noseirat	Residential	Concern about design and/or construction errors	Evaluation of structural safety of G.F Slab
13	02-2001	Gaza	Residential	Signs of deteriorations and/or defects	Assessment of a two floor building
14	03-2001	Gaza	Public	Signs of deteriorations and/or defects	Assessment of a two floor building
15	06-2001	Gaza	Residential	Concern about design and/or construction errors	Structural assessment of a two floor building

Table 4.1 (Continued)

Case No.	Date of Assessment	Building Location	Building Type	Cause of Assessment	Scope of Investigation
16	06-2001	Gaza	Public	Signs of deteriorations and/or defects	Assessment of one floor building
17	08-2001	Khanyounis	Public	Signs of deteriorations and/or defects	Structural assessment of a mosque
18	09-2001	Gaza	Public	Signs of deteriorations and/or defects	Assessment of a four floor building
19	09-2001	Gaza	Stores and residential	Signs of deteriorations and/or defects	Assessment of a two floor building
20	09-2001	Gaza	Residential	Signs of deteriorations and/or defects	Assessment of a two floor building
21	09-2001	Gaza	Residential	Concern about design and/or construction errors	Structural assessment of RC slab recently poured
22	09-2001	Gaza	Public	Signs of deteriorations and/or defects	Structural assessment of a two floor building
23	10-2001	Gaza	Residential	Signs of deteriorations and/or defects	Structural assessment of a two floor building
24	10-2001	Middle area	Public	Accidental	Assessment of a two floor building after exposed to fire
25	11-2001	Gaza	Public	Accidental	Preliminary assessment of a four floor building exposed to fire
26	12-2001	Gaza	Public	need to add additional floor	Structural assessment of a two floor building
27	05-2002	Al-Bureij	Public	need to add additional floor	Structural assessment of one floor building
28	01-2003	Gaza	Public	Signs of deteriorations and/or defects	Assessment of a four floor building
29	03-2003	Gaza	Commercial	Signs of deteriorations and/or defects	Assessment of G.F Slab
30	07-2003	Gaza	Public	Concern about design and/or construction errors	Assessment of 2nd floor
31	08-2003	Gaza	Residential	Concern about design and/or construction errors	Structural assessment of foundations after deficiency in concrete strength.
32	12-2003	Gaza	Residential	Signs of deteriorations and/or defects	Assessment of a two floor building
33	05-2004	Gaza	Public	Signs of deteriorations and/or defects	Assessment of a six floor building showing cracks after adding new floors

Table 4.1 (Continued)

Case No.	Date of Assessment	Building Location	Building Type	Cause of Assessment	Scope of Investigation
34	08-2004	Gaza	Public	Signs of deteriorations and/or defects	Assessment of a two floor building
35	03-2005	Gaza	Residential	Concern about design and/or construction errors	Assessment of 2nd floor slab
36	05-2005	Gaza	Residential	Signs of deteriorations and/or defects	Structural assessment of a four floor building
37	03-2006	Gaza	Residential	Concern about design and/or construction errors	Assessment of concrete strength of 1st floor
38	05-2006	Gaza	Residential	Signs of deteriorations and/or defects	Assessment of 5th floor apartment
39	10-2006	Beit Lahia	Stores and residential	Accidental	Assessment of ground floor exposed to fire
40	01-2007	Beit Lahia	Public	Concern about design and/or construction errors	Assessment of a three floor building

4.4 SCOPE AND METHODOLOGY OF THE CASE STUDIES SURVEY

Data were collected from assessment reports of cases carried out by various institutions and firms. The purpose was mainly to study the local practice for assessment of existing buildings in Gaza Strip, and to identify damages, their causes, and the repair methods used. The survey has been made in two steps: (1) Gathering Information, and (2) Data Analysis.

4.4.1 Step1: Gathering Information

Several visits have been made to relevant institutions and consulting firms in Gaza Strip to get possible information about rehabilitation local practice and prevailing conditions in the area. To facilitate the data collection process, a data inquiry sheet was designed in a form suitable for recording the relevant information. The following issues were addressed in the survey:

4.4.1.1 General Information

These include general information about the case itself such as the title of investigation, building type, description, location, date of construction, and the date of investigation.

4.4.1.2 Assessment Practice

Data were collected regarding the assessment main features such as scope of the assessment, the cause or causes for which the assessment is required, the main steps of the investigation, and the evaluation method used. These information are of extreme importance to enable the identification of the local assessment practice and find out the weak and strong points in such practice.

4.4.1.3 Defects and deteriorations in the structures

In each case a list of defects and deteriorations found is established with their main causes and the recommended actions suggested by the assessment team. The main purpose of these information is to identify the damages of existing structures in Gaza strip, their causes, and the repair methods used.

4.4.2 Step 2: Data Analysis

All the available case studies were reviewed. The gathered information were classified, grouped, and compiled using Excel sheets. Furthermore, statistics regarding the rehabilitation aspects such as causes of assessment, steps of local assessment practice, type of damages in existing buildings etc. were extracted.

4.5 FINDINGS OF THE CASE STUDIES SURVEY

The case studies survey has shown considerable information concerning the current situation of assessment practice and defects in existing buildings in Gaza Strip. This information has been categorized with regard to five main topics as follows:

4.5.1 Types of Constructions in Gaza Strip

Local investigations have shown that the reinforced concrete construction systems used in Gaza Strip fall within two main systems, the reinforced concrete with concrete block bearing walls system, and the reinforced concrete skeleton system. Some main features of these systems are described as follows:

4.5.1.1 Reinforced Concrete with Concrete Blocks Bearing Walls Construction System

According to the case studies survey, reinforced concrete buildings in Gaza Strip had appeared in about 1950's or earlier. Buildings in this period comprised thin two-way solid slabs with drop beams or steel I-beams supported on concrete blocks bearing walls or on drop beams resting on concrete block walls. The concrete was made of coarse and fine aggregates. The sand was mainly the sea shore sand where some shells were found in samples taken from such concrete. Reinforcing steel bars used were of the round mild steel. Fig. 4.3 gives an idea about such constructions and the used materials. Buildings from this type comprised about 28% of the surveyed cases.

(a) An old building in Gaza. (Shifa Hospital)

(b) Two-way slab with steel I-beams. (Abu Asi Building- Gaza)

(c) Core Samples from Concrete showing type of aggregates used. (Shifa Hospital)

(d) Round mild steel bars in concrete. (Abu Asi Building- Gaza)

Fig. 4.3: Components and Materials in the RC with Concrete Block Bearing Walls System.

4.5.1.2 Reinforced Concrete Skeleton Construction System

Buildings constructed in late 1970's and in the beginning of 1980's were of reinforced concrete skeleton system that used one-way or two-way slabs on drop or hidden beams supported on columns which transform loads to foundations. Shear walls or moment resisting frames were used to resist lateral forces especially in high rise buildings. The slabs were solid, ribbed, or sometimes waffle slabs. Columns were rectangular or with circular cross-section, and foundations were of various types such as single, combined, raft, etc. Cast in situ concrete and ready mixed concrete were used. Deformed steel bars were the main reinforcement, while concrete hollow concrete blocks were used in these buildings as external and internal walls.

This type of buildings was the dominant in the case studies and constituted about 72% of which more than 18% were still under construction.

4.5.2 Causes for Assessment of Buildings in Gaza Strip

Assessment of defects and errors in existing structures was requested for one or more of the following reasons as shown in Fig. 4.4:

a) Appearance of signs of deteriorations or defects in the building as a whole or in some of its parts. Cases under this cause category formed about 49% of the cases.

b) Concern about design errors, poor construction practice, and/or poor quality building materials. Cases in this category formed about 28% of the cases.

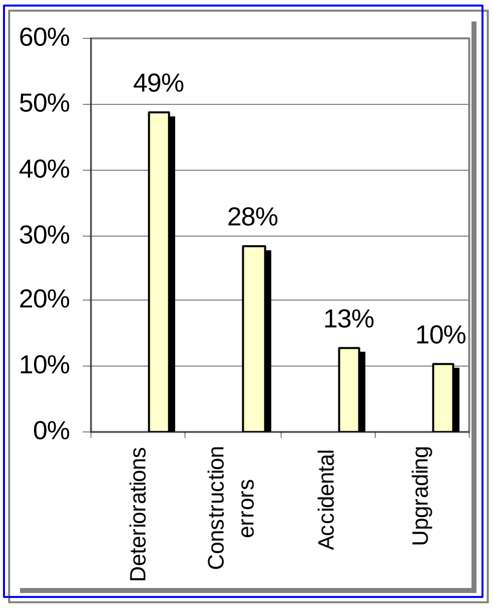


Fig. 4.4: Causes for Assessment.

c) Need to add additional floors or architectural modifications in buildings most of them have no structural drawings or materials quality control information. About 10% of the cases fall within this category.

d) Accidental causes such as fire. This category constituted about 13% of the cases.

4.5.3 Steps of Local Assessment Practice

Assessment of defects and errors in existing structures within the case studies was normally performed by experienced engineers who started their investigations by visual inspection. The assessment steps involved in the case studies comprised one form of the following regimes shown in Fig. 4.5:

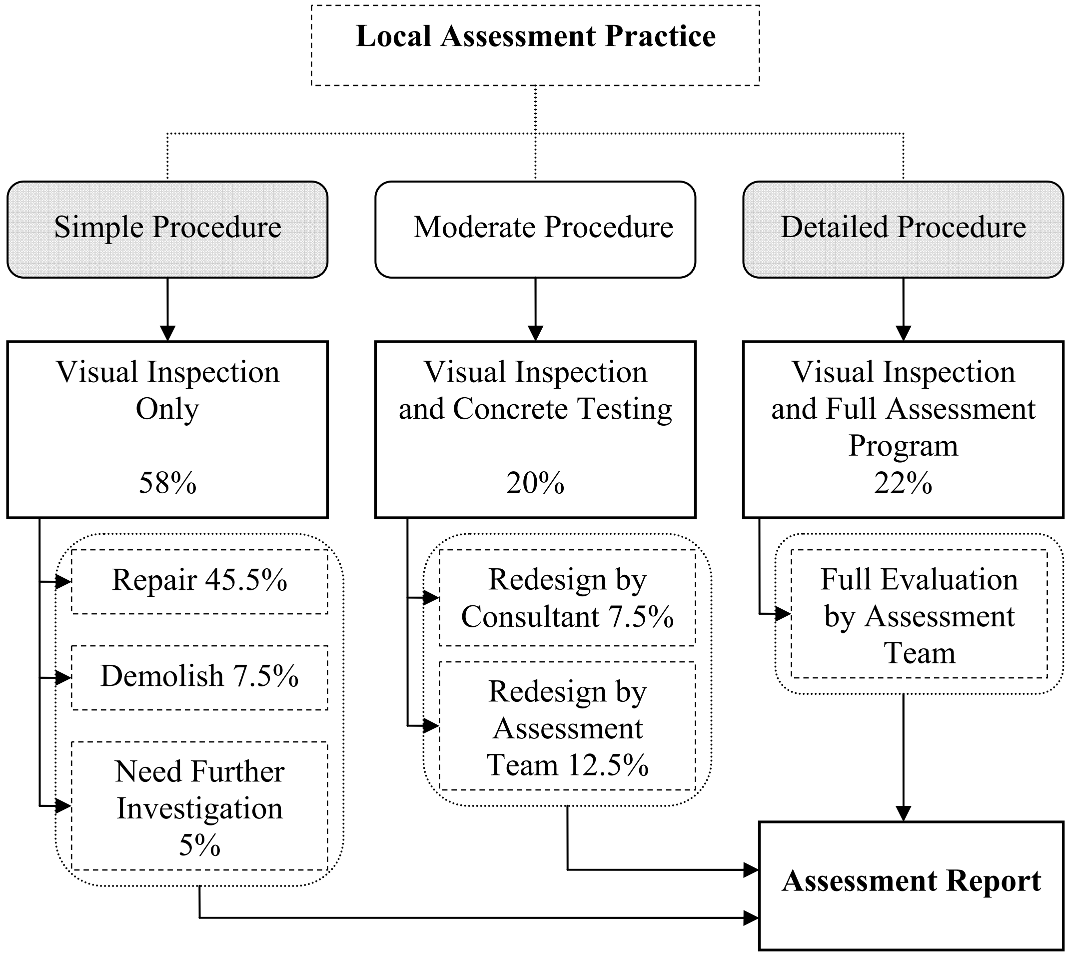


Fig. 4.5: Steps of Local Assessment Practice.

4.5.3.1 Simple Procedure

In about 58% of the cases, visual inspection was the unique step performed. In these cases it was discovered that one of the following situations dominated:

i. The defects were of minor effect on the structural safety, and could be repaired or rehabilitated using appropriate methods with no need for further complications in 45.5% of the cases.

ii. The damages were excessive and severe such that the repair or rehabilitation works were not feasible in 7.5% of the cases. The most appropriate solution was to demolish and rebuild the whole structure or the parts under consideration.

iii. The situation couldn't be assessed without a more detailed investigation, and a new budget was needed to complete the assessment. In these cases no indications of the owner's agreement were found in 5% of the cases.

4.5.3.2 Moderate Procedure

Concrete compressive strength of existing structural elements was determined using non destructive test methods such as ultrasound or impact hammer. In some cases destructive methods such as concrete core samples were used. Both of the testing methods were considered essential to evaluate the concrete strength of existing structures in about 20% of the cases, in addition to the visual inspection of defects. After the strength tests had been performed, the assessment team evaluated the test results, and judged the in situ compressive strength of concrete. Also the structural adequacy was evaluated using structural analysis and re-designs.

4.5.3.3 Detailed Procedure

For about 22% of the cases, a full investigation program was carried out. The investigation program included some or all of the following activities:

i. Surveying works.
ii. Exploration of foundations and measurements of dimensions.
iii. Soil testing and assessment of soil bearing capacity.
iv. Site and laboratory testing of concrete strength in various structural elements.
v. Laboratory testing of steel reinforcing bars for samples cut or separated from the structure.

In these cases a complete assessment report was prepared by the assessment team including all the findings and recommendations.

4.5.4 Description of Defects in Existing Buildings in Gaza Strip

Identification of damages in existing buildings in Gaza Strip and their causes were the main objectives of the case studies survey to enable development of the assessment approach. For example, if the study shows that there are no detected damages resulting from aggregate silica reactions, it is appropriate not to consider methods of assessment and repair techniques for such damages in the proposed assessment approach.

The case studies revealed several types of defects that had occurred in existing buildings under consideration. The causes of these defects are related to different factors. Grouping and classification of defects encountered in the survey was selected to relate defects to their direct causes as follows:

4.5.4.1 Defects Caused By Deterioration of Concrete and Reinforcement

The deterioration damages detected in the case studies shown in Figs. 4.6 to 4.11 were caused by deteriorations in concrete, corrosion of reinforcement, or both. The damages were in one or more of the following forms:

i. Disintegration of concrete close to ground or to a water source, due to probable chemical reaction indicated by weakness of mortar, roughness of concrete surface, and appearance of coarse aggregates at the surface. Fig. 4.6 illustrates such damage. This type was rare in the case studies and no efforts were made to determine its real cause by laboratory testing.

ii. Signs of steel corrosion indicated by the appearance of rust on the concrete surface as shown in Fig. 4.7 were caused by the penetration of water into concrete.

iii. Cracking along steel bars due to steel corrosion as in Fig. 4.8.

iv. Spalling of concrete cover in some locations such that shown in Fig. 4.9.

v. Complete spalling of concrete cover and appearance of corroded steel as in Fig. 4.10. Some cut off bars may be encountered.

vi. Corrosion of steel bars due exposure to environment as in Fig. 4.11.

Fig. 4.6: Deterioration of Concrete.

Fig. 4.7: Appearance of Rust on Surface.

Fig. 4.8: Cracks along Steel Bars.

Fig. 4.9: Local Spalling of Concrete Cover.

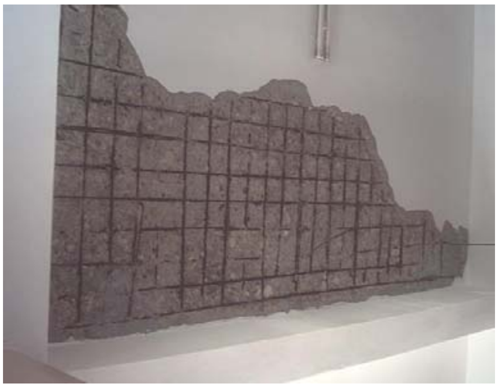


Fig. 4.10: Complete Spalling of Concrete Cover.

Fig. 4.11: Corrosion of Exposed Steel Bars.

4.5.4.2 Defects in Structural Elements Caused By Other Factors

Several types of defects and cracks in main structural elements such as slabs, columns, or bearing walls were encountered in the case studies. They were caused by various causes other than progressive deterioration. They were in one or more of the following forms:

i. Vertical and inclined cracks in bearing walls at the corners due to settlement of foundation or sub-base and due to stress concentration at openings (Fig. 4.12).
ii. Cracks in external walls and in bearing walls under ground beams due to settlement (Fig. 4.13).
iii. Vertical cracks in drop beams as a result of over loads, section deficiency, and/or low strength materials (Fig. 4.14).
iv. Cracks in slabs, columns, and walls at expansion joints due to differential settlement of foundation as a result of additional floors or improper assessment of soil bearing capacity (Fig. 4.15).

v. Horizontal cracks in columns, vertical cracks in slabs, and inclined cracks in walls due to foundation settlement as a result of the effect of over loads due to excavation very close to an existing building or imposing additional loads on foundations due to an adjacent new constructions (Fig. 4.16).

Fig. 4.12: Vertical and Inclined Cracks in Bearing Walls.

Fig. 4.13: Vertical and Inclined Cracks in Bearing Walls under Ground Beams.

Fig. 4.14: Vertical Cracks in Drop Beams.

Fig. 4.15: Differential Settlement Cracks at Expansion Joints.

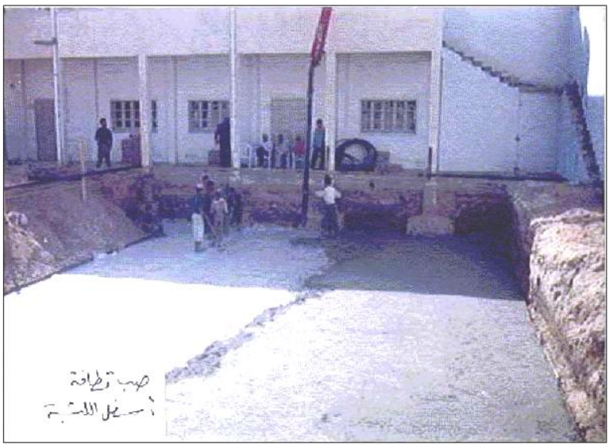


Fig. 4.16: Excavation to Foundation Level of an Existing Building.

4.5.4.3 Defects in Non Structural Elements

Minor defects in non structural elements that didn't affect the structural capacity were encountered in most of the cases such as cracks between concrete elements and concrete block works shown in Fig. 4.17, which normally appeared as a result of variation of thermal expansion characteristics between concrete and block, in addition to a weak bond between the two materials or improper building practice. Others are associated with deflection of the wall sub-base or foundation settlements in case of sandy soils. Also craze cracking are sometimes found in external walls plastering due to improper curing or weak plaster mortar as shown in Fig. 4.18.

Fig. 4.17: Horizontal Cracks Between Windows Concrete Lintel and Block Works.

Fig. 4.18: Craze Cracks in External Plaster.

4.5.4.4 Other defects

Many other defects occurred in buildings due to different causes such as dampness, inadequate compaction, or excess vibration of concrete, etc. Some of these defects are illustrated with photos in Table 4.2.

4.5.5 Statistics of Defect Types and Causes in Existing Buildings in Gaza Strip

Defects and their causes are inter-related to each other. Some defects may appear as a result of a direct cause which may be considered as a defect resulting from another cause. For example, dampness which is a defect that may be caused by inadequate water proofing or tightness may be a cause of other defects such as reinforcement corrosion or concrete deterioration. Also some design errors such as improper assessment of soil bearing capacity or faults in estimating the imposed loads could be a cause of foundation settlements which in turn causes various types of structural cracks.

Table 4.2: Samples of defects in existing buildings in Gaza Strip

Defect	Cause	photo
Formation of laitance	Dampness	
Settlement and deflection of tiles	Settlement of sub-base or foundation	
Blistering of internal paint	Moisture	
Voids in concrete and appearance of steel	Inadequate compaction	
Low strength concrete	Production errors or addition of water to the ready mixed concrete during casting	
Honeycombing of concrete	Inadequate compaction, or excess vibration	

In the survey, all the damages and defects listed in the case studies were compiled and classified into groups of similar nature. They were related to their direct cause which may be a defect by itself. Table 4.3 shows the types of defects encountered. Their quantities were portioned in percentage relative to the total number of defects grouped through the case studies survey.

Table 4.3: Types of defects in existing buildings in Gaza Strip

Defect Type	**Percentage of defects %**
Dampness	14.4
Severe deteriorations and damages	14.4
Structural cracks in slabs and drop beams	9.6
Spalling of concrete cover	9.6
Cracks in block works only	8.7
Hair cracks in concrete or block	7.7
Cracks and spalls in plaster layers	6.7
Deflection, rotation, and/or distortion of structural elements	5.8
Signs of steel corrosion	5.8
Defects in electrical installations, tiles, paint, etc	5.8
Low strength concrete	4.8
Cracks between concrete and block	3.8
Instability and rotation of the structure	1.9
Variation of color of concrete surface	1.0

The defects vary in their severity. Dampness which is a minor defect constituting 14.4% of the defects, was considered as an additional cause of more severe deteriorations and damages such as concrete deterioration, steel corrosion, or even reinforcing bars cut off (also 14.4%). Cracks are common in existing buildings, they can be hair cracks in concrete (7.7%), cracks in plaster (6.7%), cracks in block works only (8.7%), cracks between concrete and block (3.8%), and more critical in slabs and beams (9.6%). These cracks reached advanced conditions that caused spalling of concrete cover (9.6%).

Table 4.4 lists the causes of defects in existing buildings in Gaza Strip. The first cause was concrete deterioration and reinforcement corrosion. Concrete deteriorates as a result of probable chemical attacks of salts (chlorides or sulfates ions) impregnated in water which penetrates into concrete elements or is induced in the concrete mix. In addition, the ingress of water and other chemicals into concrete result in corrosion of reinforcing steel which in turn causes cracking of concrete and spalling of its cover to reinforcement. This was found in about 31% of defect causes.

Table 4.4: Causes of defects in existing buildings in Gaza Strip

Defect Cause	Percentage of defects %
Deterioration mechanisms and steel corrosion	30.8
Construction errors in the building	26.9
Fire	16.3
Foundation settlements	7.7
Low strength concrete	5.8
Effect of adjacent new constructions	4.8
Water seepage and dampness	3.8
Design errors	2.9
Lack of maintenance	1

Another important factor causing defects in the buildings is the construction errors such as excess or inadequate compaction, errors in formworks, addition of water to concrete during casting, and lack of engineering supervision. This factor constituted about 27% of defect causes.

On the other hand accidental factors such as fire had a considerable effect on the existing structures (16.3 %).

Only about 3.0% of the defects were caused directly by design faults. Over loading, or improper assessment of soil bearing capacity resulted in settlement of foundation for 7.7% of the defects, and defects in adjacent buildings for about 5%.

Low strength concrete was a cause of about 6.0% of the defects, and about 4.0% of the defects were caused by other factors.

4.5.6 Local Practice for Repair

Recommendations associated with the encountered defects were given at the end of the assessment reports. The assessment team was able to give definitive recommended actions in about 95% of the cases after visual inspection with or without concrete testing, or after a complete assessment program. Only in 5% of the cases they suggested more detailed investigations to complete the assessment.

With regard to the defects, various recommendations were given in the case studies. Table 4.5 summarizes these recommendations. Rehabilitation works including repair of structural defects and/or strengthening of some elements were recommended for about 33% of the defects. Repair of non structural cracks or minor defects was recommended for about 28 % of the defects, while protective action of water proofing for concrete having a less strength than required in project specifications was recommended in about 6% of the defects. It should be mentioned that about 21 % of the defected locations with severe defects and deteriorations required demolition and rebuild either for the whole structure in some cases or for some structural parts in other cases. About 4 % of the defects which resulted from excess loading required reduction of loads or removal of one or more floors. For the remainder of defects (8.7 %) the assessment team needed further investigations to suggest a solution.

Table 4.5: Recommended Actions adopted by the Assessment Teams

Adopted actions	**Percentage of defects %**
Rehabilitation	32.7
Repair of minor defects	27.9
Demolish and rebuild	21.2
Water proofing to concrete	5.8
Reduction of loads	3.8
Detailed investigation is required	8.7

With respect to the recommendations of rehabilitation or repair in general, few cases were found to have adequate details of rehabilitation or repair works in the assessment report. Most of the reports that recommend rehabilitation or repair defer this job to qualified engineering consultants and experienced contractors; hence the application of repair or rehabilitation work is not dealt with in these assessments. This may be because of the limited scope or budget of the assessment or related to the policy of the institution or firm dealing with such assignments.

4.6 GENERAL REMARKS RELATED TO THE CASE STUDIES

The case studies survey gave a general idea and background information about current situation of rehabilitation practice for existing buildings in Gaza Strip. Valuable information were found regarding the assessment methods used, the types of damages, and their causes.

Although the technical reports found during this survey were a good source of information that enabled the compilation and identification of defects occurring in existing buildings in Gaza Strip, the following comments and notes were extracted to identify strong and weak points in the local practice regarding the assessment steps, the identification of damages, and testing practice**:**

4.6.1 Assessment Steps

The buildings in which defects or damages had occurred were either private residential or public low rise buildings. The total value of such buildings and the state of damages played an important role in limiting the assessment methods to simple and preliminary investigations with limited in-situ and laboratory tests mainly concerning concrete strength.

A site visit was the only action applied in many cases then recommendations were given depending on experience of the assessment engineers. This situation might be understood in the cases where severe deteriorations and defects are present and the rehabilitation or repair is not feasible. Also it can be recognized in the cases of minor defects that can be repaired easily without the need for additional assessment efforts. But in other cases where appreciable defects and deteriorations are present, more investigations are usually required to find out the type and extent of damage in order to relate symptoms to causes and find suitable solutions to such problems.

4.6.2 Identification of Damages

Many reports consisted of not more than one or two pages, and gave a general description of the team observations without going into details of damages or defects, their description, extent, causes, and the methods of repair in a scientific manner. For example the following paragraphs are translations to some statements in samples of such reports:

4.6.2.1 Example No. 1

> *"There are vertical and inclined cracks in the eastern part of the building"* **(Case No. 17)**.

The statement refers to the presence of cracks, without giving a scientific description such as: their width, length, depth, and their location whether in structural or non structural element in the eastern part. Also no information about the state of the cracks is given, whether they are stable or may be continuous.

4.6.2.2 *Example No. 2*

"The building consists of a three shops in the ground floor covered with old concrete slab with steel I-beam and supported on bearing walls approximately 40cm thick. There are cracks in the plaster of some bearing walls and a longitudinal crack in the slab parallel to the steel I-beam. There is a possibility to add a first floor to be used as a commercial exhibit covered with reinforced concrete slab" **(Case No. 10).**

The paragraph describes the observations, without identifying the severity of the cracks then recommends the addition of one floor without describing how the team assessed the situation. Indeed several questions can arise in such case:

a- Are the cracks structural or non-structural?
b- Do they affect the slab structural capacity or not?
c- Should the described cracks be repaired and how?
d- What are the materials and structural considerations that enabled the judgment of the ability of the structure to support an additional floor?

The report have to give at least brief answers to such questions, and should be prepared in a professional way to reflect the engineering assessment and evaluation efforts made.

4.6.2.3 *Example No. 3*

"There is a crack in one of the ground floor columns and could be repaired using suitable materials" **(Case No. 19).**

This paragraph announces the presence of cracks and recommends repair with suitable materials that are not mentioned in the report and the repair method also is not identified.

4.6.3 Testing Practice

Many cases were completed based on experience of the assessment engineers with no testing, or with limited non destructive concrete tests. However, concrete core tests were performed in some cases.

In cases of concrete deteriorations resulting from probable chemical attacks, and cases of reinforcement corrosion, it was noticed that no chemical tests were performed. The common intervention was the removal and reconstruction of these locations if they comprised small areas or portions within the structure, or demolition and rebuild all the structure if they comprised large areas.

In many cases, for example fire, although dangerous damages were found, the team recommended repair or rehabilitation without any testing of concrete or reinforcement, in addition to the absence of any details for such repair or rehabilitation works. The following is an example of such cases where more investigations may be necessary:

> *"Many parts of slab internal plaster have been spalled out as a result of fire. Also slab hollow blocks have fallen in some locations, in addition to spalling of concrete cover at some ribs and beams in some slab locations. All the mentioned defects can be repaired according to the attached table"* **(Case No. 1)**.

In this case, although fire duration or burned materials were not mentioned in the report, and the effect of fire on reinforcement steel or concrete was not investigated, a repair practice was suggested.

4.7 CONCLUSIONS OF THE CASE STUDIES SURVEY

The case studies survey has shown considerable information concerning deteriorations and defects occurring in existing buildings in Gaza Strip, in addition to information about the assessment practice by local institutions and expert consultants. The conclusions of this survey are very important and should be taken into consideration while proposing an assessment approach suitable for use in Gaza Strip. The following are main conclusions:

4.7.1 Causes for Assessment of Existing Structures in Gaza Strip

Assessment of existing structures in Gaza Strip had been requested for different causes such as one or more of the following:

1. When the owner required change of use of a building other than the previous use, increase of floors, or structure enlargement, etc.
2. Appearance of signs of deteriorations or defects that could be noticed by the owner thus doubts about the safety of the building arise.
3. Damage due to extreme loading events such as explosions, fire, etc.

4. Concern about design, construction errors, or quality of materials and workmanship.

4.7.2 Causes of Damages in Existing Structures in Gaza Strip

It was revealed form the survey that the damages and defects in existing building are related to one or more of the following causes:

i- Exposure conditions in Gaza Strip. These conditions such as temperature, relative humidity, and concentration of salts in the atmosphere, played an important role in deterioration of concrete and hence corrosion of reinforcing steel.

ii- Construction errors, deficiency of concrete strength, and sometimes design faults have constituted a considerable cause of defects in existing structures. These were fortunately discovered in their early stages before causing more progressive or severe problems in such buildings.

iii- Impact and accidental events were the causes of many problems in existing structures. Some of these problems were minor and could be repaired easily in some cases, but in most of the cases they constituted severe situations in which destruction to some parts or even to all of the building has occurred.

It should be mentioned that manmade destructions resulting from Israeli military invasions comprise important damage causes in existing buildings in Gaza Strip that result in completely or partially destroyed buildings the matter that adds further complications and causes multiple types of destructions.

For these reasons, an assessment method should be proposed to be appropriate to the prevailing conditions. The assessment engineers have not only to follow planned regimes of assessment suitable for the case or cases under consideration, but also should have the adequate knowledge of defect types, causes, and, how they are repaired, in order to accurately diagnose the defects and find suitable solutions to such problems.

4.7.3 Type and Extent of damages in Existing Structures in Gaza Strip

With regard to the defects occurring in existing buildings, it was found that these defects are of different types and with varying degree of seriousness. Some of them start as minor, but may progress with time to the form of severe deterioration. For example, wetting or dampness in concrete is considered as a minor defect in its early stages, but when it lasts a long period of time it can cause steel corrosion and hence spalling of concrete cover which results in a reduction of section capacity where structural failure or building collapse may occur. In such cases the condition assessment of a defected or deteriorated structure has to be thorough and precise. The assessment engineer has to describe the defects correctly and in a systematic way representing the degree of seriousness of the defects.

4.7.4 Assessment Reports

Technical reports prepared by the assessment teams were of different formats and some of them did not contain essential information regarding the cases under consideration. This has led to misunderstanding the problem and reduced the technical value of such reports. For this reason, a proposed list of important items that should be included in the assessment report will be presented in this research.

4.7.5 Local Assessment Practice

The assessment methods used in Gaza Strip were of simple, moderate, or detailed nature according to the case under consideration. This comprises a strong point of assessment since the exerted efforts should be proportioned to the current situation and total value of the case considered. But in some cases, the assessments were roughly shortened such that the problems were not diagnosed efficiently with confidence and the decisions were not properly justified. The assessment practice in these cases was very simplified to the extent that it became unsatisfactory and the following shortcomings were pointed out:

1- Some cases were assessed based on team experience only while the situation required more in depth investigations.

2- Scientific methods for identification and description of damages such as their causes, types, extent, etc. were not followed in many cases.

3- Little efforts were exerted regarding the details of repair and rehabilitation methods to be used in correcting the encountered problems.

4- Limited concrete testing were used although, accurate assessments usually need various types of tests for proper identification of damages in existing structures.

5- Various assessment practices were in use and no unified assessment method was followed by the assessment engineers in Gaza Strip.

Furthermore, there was no information at the institutions responsible for the assessment regarding their recommendations if they were applied or not. This situation may have to be studied in further research work to find out if it is important for the assessment engineers to follow up the application of their recommendations or not.

CHAPTER 5: PROPOSED ASSESSMENT APPROACH FOR EXISTING STRUCTURES IN GAZA STRIP

5.1 INTRODUCTION

Several methods for assessment of existing structures were found in literature. These methods were designed to suit various national circumstances and prevailing conditions. So they were of varying degrees of sophistication proportional to the types of constructions, types of damages, and the extent of deteriorations. In developing the assessment approach for Gaza, several criteria were considered as follows:

1- Simplicity, straight forwardness, and economy.
2- Directed to the main types of damage in Gaza Strip.
3- Can be used for all causes of assessment.
4- Can be implemented by a small rehabilitation team from various institutions with various technical backgrounds.
5- Compatible with the latest development in assessment worldwide standards.

The developed assessment approach uses a planned regime of inspection and testing. It could be followed by suitably experienced and qualified engineers to assess the condition of the structure, understand the causes of damage, and select a repair method that is appropriate for both rectifying the existing defects and resisting future deterioration. The approach enables the following objectives:

1- Assess the condition of the structure and identify the defects.
2- Understand the cause or causes of damage.
3- Decide on the intervention action.
4- Recommend and specify the optimum solution of the problem.

5.2 GENERAL DESCRIPTION OF THE PROPOSED ASSESSMENT APPROACH

The proposed assessment approach consists of three routes according to the needed assessment efforts, with five main steps as shown in Fig. 5.1. Since the steps are designed to be sequential in time, each one depends to a large extent on the previous steps.

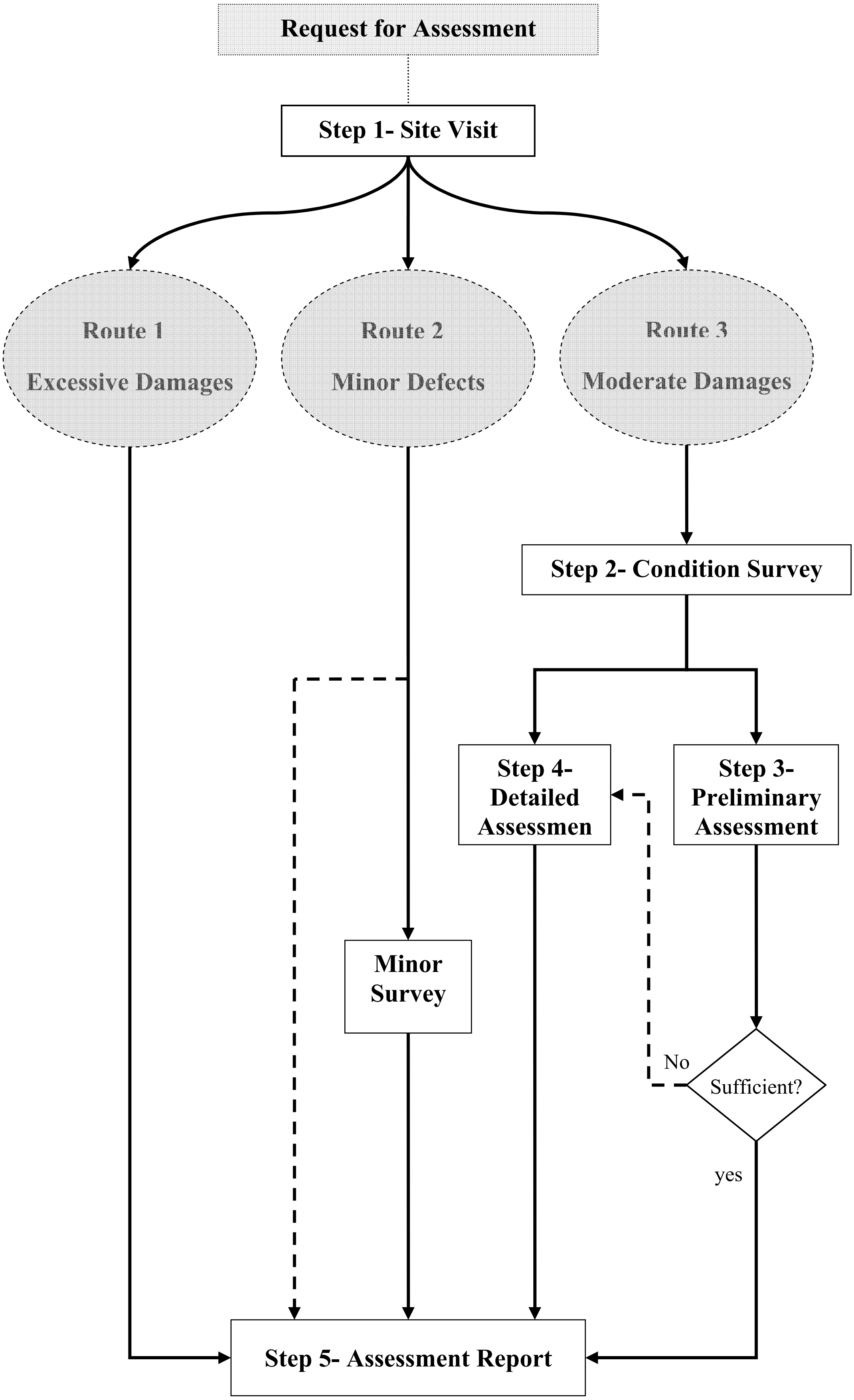


Fig. 5.1: Schematic Diagram of the Proposed Assessment Approach.

The assessment process as a whole and the involved steps in particular depend largely on the scope of assessment, the owner's requirements, and the budget constraints. The starting point of the proposed assessment approach is the site visit from which three different routes can arise according to the extent of damage. Generally each route consists of a number of steps. The steps consist of activities which may have several tasks.

5.2.1 Routes

Three routes are proposed. The selection of which route to follow depends on the type and extent of the detected damage determined by the assessment team after the site visit. Different rehabilitation teams could in some cases reach different conclusions related to the assessment of the condition of the structure and hence the selection of the appropriate route depending on their relative experiences, building importance, assessment consequence cost, and owner's expectations, etc. Nevertheless, the following criteria will help the assessment teams to decide on the route category:

Route 1- Excessive Damages: In some cases where excessive and severe damages are found propagating in the building such that rehabilitation could not be feasible, no further investigations are needed. In this case demolition of the building or the elements under consideration is the only appropriate intervention action.

Route 2- Minor Defects: For the cases where minor defects such as defects in concrete finish, blistering, hair cracks, etc. are encountered, the defects could be described, located and quantified during the site visit or in a minor survey. Then a report is prepared containing complete description of the case, and suggestions of repair methods for the encountered defects.

Route 3- Moderate Damages: This is the main route of assessment. It could be followed in the cases where damages can not be readily assessed by experience, and need to be more precisely investigated before rehabilitation. In such cases, several steps are needed to map and appraise the damage, evaluate the current condition of the structure and prepare the recommended actions.

5.2.2 Steps

The main assessment steps are:

Step 1- Site Visit.

Step 2- Condition Survey.

Step 3- Preliminary Assessment.

Step 4- Detailed Assessment.

Step 5- Assessment Report.

5.2.3 Activities

Each step generally constitutes three related activities, planning, implementation, and evaluation as shown in Fig. 5.2. Before starting any assessment step, some preparation and planning is required in order to identify why, what, and how to do. Next the step is implemented as planned then findings are evaluated to determine the next step.

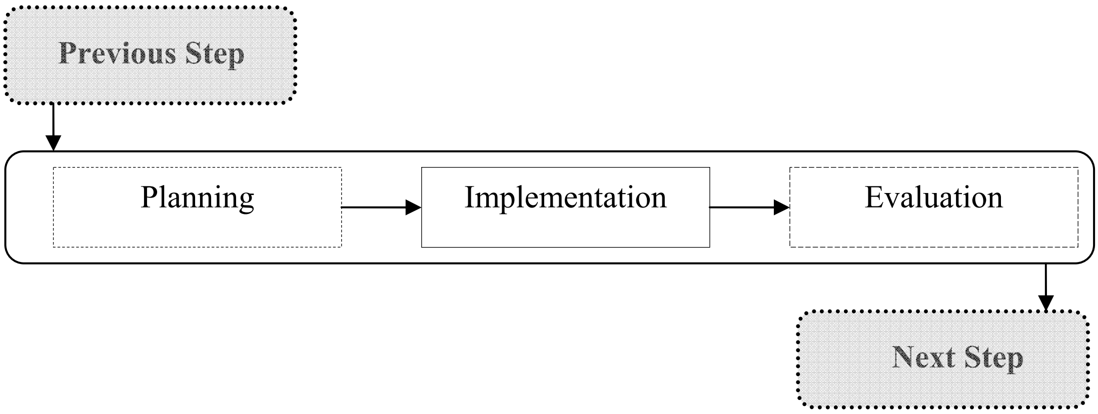


Fig. 5.2: Typical Activities of an Assessment Step.

5.2.4 Tasks

The activities of each step comprise a number of tasks. These tasks vary from an activity to another according to the case under consideration.

5.3 DETAILED DESCRIPTION OF THE APPROACH

The assessment main steps are discussed in reference to Fig. 5.1 as follows:

5.3.1 Step 1- Site Visit

A site visit is essential for any assessment. It is the key which opens or closes the process. It aims to let expert's eyes identify the case and take an initial impression regarding the condition of the structure. As shown in Figs.5.2 and 5.3 it consists of three activities: Preparation, Implementation and Evaluation.

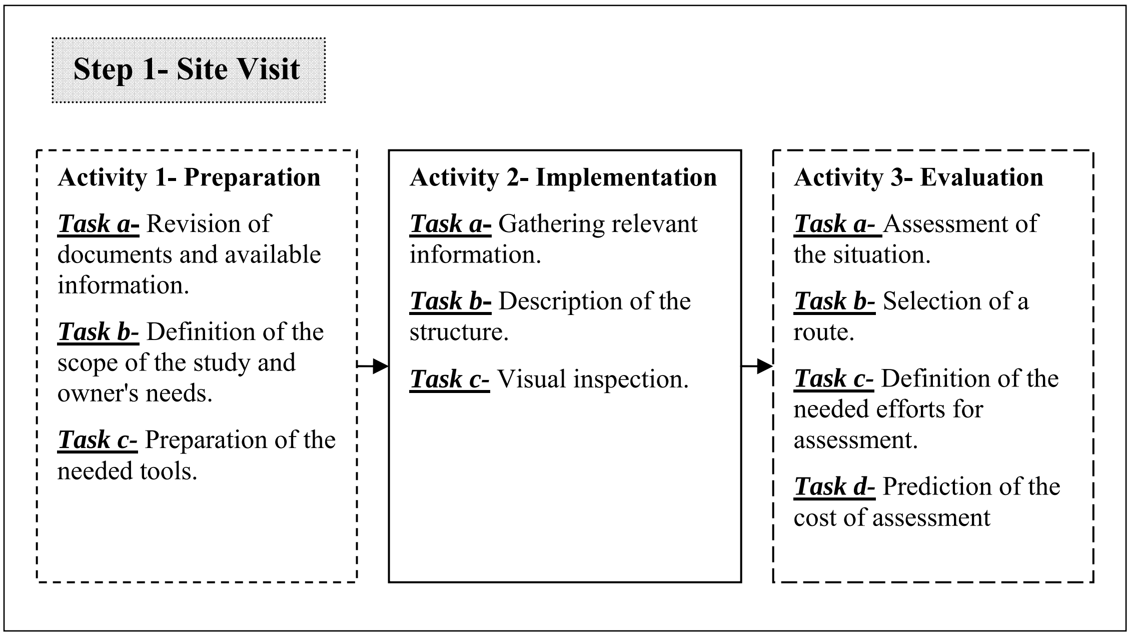


Fig. 5.3: Activities of the Site Visit.

Activity 1- Preparation

The preparatory work for the site visit comprises the following tasks:

Task a- Revision of documents and available information taken from the owner, such as drawings of the building, previous test results, information about the problem, etc. This makes an initial background about the case.

Task b- Definition of the scope of the study according to the owner's needs by meeting the owner, listening to his complaint, and understanding his objectives.

Task c- Preparation of the needed tools to be used during the site visit such as a camera, a tape, a hammer, etc.

Activity 2- Implementation

During the site visit the following tasks are to be performed:

Task a- Gathering relevant information about the structure and collection of data concerning the problem, such as the type of building, its use, date of construction, first appearance of defects, etc. These information can be obtained from the owner or perhaps from other concerned people who may be met at site. Resident people may give valuable information about the problem and when they noticed it.

Task b- Description of the structure and the surrounding structures to be made during the site visit such as its location, dimensions, number of floors, environmental conditions, etc. The assessment team verifies the existing building with plans and drawings (if any); otherwise makes the necessary measurements and surveying works to maintain as built drawings.

Task c- Visual inspection of the structure, which is the most effective qualitative method for the evaluation of structural soundness and identifying the typical distress symptoms together with the associated problems. A walk through the structure with eyes on any unusual defect keeping in mind the background information about the problem, that determines to a large extent what to look for, will provide valuable information regarding workmanship, structural serviceability and material deteriorations. It is always necessary to carry a camera during such visit to take necessary photographs of the distressed structure and its members.

Visual inspection and collection of data would be helpful in planning the entire assessment. In some cases the site visit may be sufficient to conclude that the rehabilitation is not feasible such as in the cases of excessive damages. In other cases of minor defects such as hair cracks in plaster or block works, dampness in some locations and local defects in non-structural elements, the assessment team may find out that there is no need for the owner's suspicions since the defects are usual and could normally occur in any building.

Activity 3- Evaluation

After the site visit is completed the assessment team performs the following tasks:

Task a- Assessment of the situation, by deciding if damages or deteriorations are present and need to be assessed or not. If damages make the structure unsafe for the users, the assessment team has to determine any immediate safety measures to be considered such as supporting some elements, closure of some parts of the building, or even evacuation of the whole building until the completion of the assessment and repair.

Task b- Selection of a route to be followed in accordance with the damage extent. Three cases may be found: the damages are excessive, minor, or moderate. For each case a route of assessment can be followed: Route 1, Route 2, or Route 3 respectively.

Task c- Definition of the needed efforts for assessment according to the structure condition as judged during the site visit and the selected route. These efforts vary from a case to another, and comprise several actions such as testing, surveying works, excavation, etc. It is important in this case to have a good prediction of such efforts since they are directly related to the estimation of the cost of assessment. Experience of the team plays an important role in such issue.

Task d- Prediction of the cost of assessment as a preliminary estimate should be made roughly at this stage but to an acceptable degree of accuracy in order to negotiate with the owner and take his approval.

Thus, on completion of the site visit the assessment team has three routes to choose from as follows:

5.3.1.1 Route 1: Excessive Damages

In some cases, the site visit determines that it is not desirable to proceed with further assessment steps. This may happen in:

a- The cases of excessive damage and progressive deteriorations where repair materials are not available, or the estimated cost of rehabilitation works may approach that for demolish and new build option.

b- The cases in which the owner's objectives cannot be satisfactorily met, or the structural integrity cannot be restored without major alteration of the serviceability of the building such as for example, column jacketing or section enlargement to the matter that may affect the accessibility or function of the structure.

In these cases the assessment team has to evaluate the findings of the site visit. Several factors can be considered in this evaluation such as cost of repair options compared with the cost of a new construction, availability of repair materials, availability of suitable repair technique, and availability of qualified contractors, etc. Among these factors usually the cost estimate of rehabilitation works compared with the cost of demolition and re-build option determines the case. This can be done mainly by experience of the assessment team.

This route is directly branched from Step 1 (Site Visit) to Step 5 (Assessment Report) without passing any other steps.

5.3.1.2 Route 2: Minor Defects

Sometimes only minor defects are encountered during the site visit. Minor defects are those defects not related to structural integrity or do not affect structural capacity such as defects in concrete finish, blistering after concrete placing, hair cracks, crazing, drying shrinkage cracks, light cracks between block and concrete, cracks in partition concrete block walls, or dampness of concrete in its early stages. These defects once found, can be assessed directly by experience of the assessment team or have to be more investigated to find out their real causes, located, quantified, and described during the minor survey step that is described as follows:

Minor survey: is the step of identifying and describing minor defects encountered in a building by means of visual inspection and some measurements. These measurements include identification of boundaries of the defected areas, length of cracks, location of dampness, etc. Sometimes it is essential to exert some efforts to explore the source of defect as in the case of wetting or dampness, or to make some exploratory removal of some parts to uncover hidden objects, for example false ceilings that may hide some defects or blistering areas which may be caused by steel corrosion.

After the site visit, this route may go directly to the assessment report, or passes through the minor survey according to the case. The assessment report then should describe the findings and explain the methods of repair for the encountered defects.

5.3.1.3 Route 3: Moderate Damages

This route comprises the main branch of the assessment approach. It can be followed in the cases where the site visit reveals that various types of damages or defects are found, and the structural condition can't be readily assessed. It arises in many circumstances. The following are some examples:

i. Cases that show damage due to excess or improper loading, explosions, vibrations, fire, or other causes.

ii. Structures where there is evidence of deterioration or structural weakness, such as excessive cracking, spalling of concrete, corrosion of reinforcement, excessive deflection of some members, rotation, or other signs of damage.

iii. Cases that need assessment for change of use or upgrading especially when no adequate information regarding the used materials strength or structural details are available.

iv. Cases of concern about quality of building materials, design, or workmanship.

In such cases the assessment procedure comprises the following steps:

5.3.2 Step 2- Condition Survey

The Condition Survey is an examination of the structure for the purpose of locating and identifying areas of distress. It includes a mapping of the various types of defects that may be found, such as cracking, surface problems (disintegration, spalling, etc.), and deteriorations. The activities within the condition survey are illustrated in Fig.5.4:

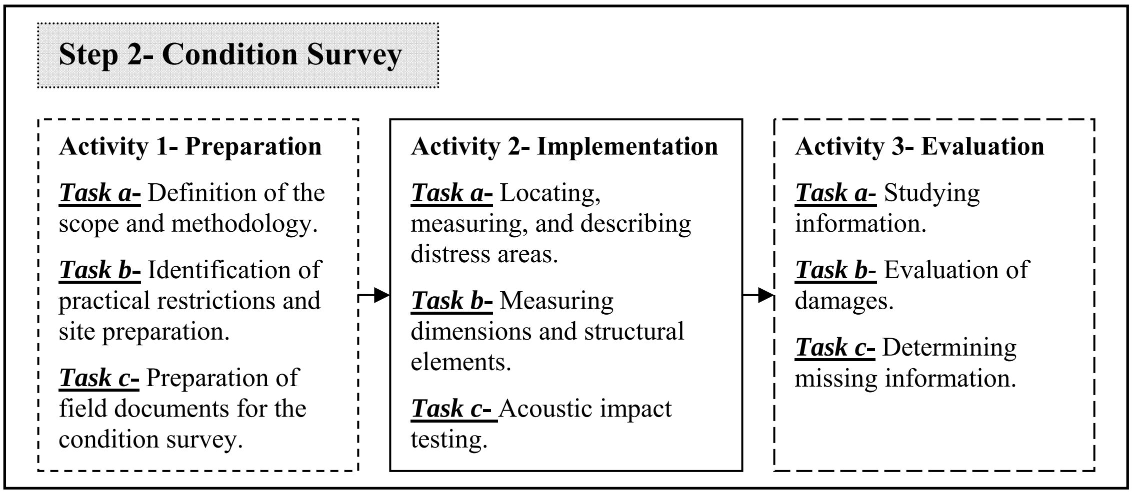


Fig. 5.4: Activities of the Condition Survey.

Activity 1- Preparation

Before starting the condition survey essential preparation and planning comprise the following tasks:

Task a- Definition of the scope and methodology of the condition survey keeping in mind the results of the site visit and the owner's needs.

Task b- Identification of the practical restrictions in conducting the condition survey and devising methods to overcome them- Such restrictions may be as closure of entrances of some places, no access to some locations such as floors or roof, and covering of some elements, etc. It is important also to define the safety measures for the condition survey team, and make necessary site preparations including access scaffolds, and working platforms, etc.

Task c- Preparation of field documents for the condition survey such as photocopies of available drawings (if any), work sheets and tables for recording field data, and a list of tasks with a work schedule.

Activity 2- Implementation

The following tasks are to be performed during the condition survey:

Task a- Locating, measuring, and describing distress areas including the description of damages, and measurement of cracks length, width, and depth. The assessment team has to concentrate on areas of critical sections in the building such as corners, wall openings, internal and external columns, mid-spans, and elements located close to the ground, etc. Also the team has to identify any noticeable damage. All the detected damages have to be clearly located on the available plans or at least on sketches of these plans. Furthermore, photographs of the damages and defected locations are valuable information for assessment in the later steps.

Task b- Measuring dimensions and various structural elements- This is to verify the measured dimensions with the available drawing details. If drawings are available, samples of spans length, and structural elements dimensions can be adequate to verify the as-built construction, otherwise adequate measurements and surveying works have to be made at least to reproduce plans to an adequate accuracy for the purpose of locating and describing damages.

Task c- Acoustic impact testing in several locations to identify if hidden damages are present or not- This is done by the assessment team using a hammer by applying slight knocks on the concrete surface at different locations and comparing the resulting sound from a location to another.

Activity 3- Evaluation

Evaluation at the end of the condition assessment comprises the following tasks:

Task a- Studying all the information gathered during the previous steps. This is done by categorizing the information into categories such as those related to the description of the case, the damages (types, sources, and causes), properties of construction materials, the strength of the structure, and its serviceability, etc.

Task b- Evaluation of damages- All the encountered damages have to be assessed regarding their real causes, extent, and effect on the structure. Based on the previous information and the assessment of damages the team can identify the needed assessment efforts.

Task c- Determining the missing information- According to needed assessment efforts determined in the previous task, the missing information that are needed to complete the assessment can be determined.

At this stage the team has to select the next step either the preliminary or the detailed assessment. This selection depends on several factors such as:

i. The scope of the assessment.
ii. The type and extent of damage.
iii. The amount of missing information needed.

If the assessment team is not certain which assessment to follow, it is recommended to start with the preliminary assessment, then evaluate if a detailed assessment is needed or not. Generally the cases that can be assessed in the preliminary assessment are those cases in which most of the needed information can be found at the condition survey level, and those having less severe damages.

5.3.3 Step 3- Preliminary Assessment

The objectives of the preliminary assessment are to assess the condition of the structure, set the rehabilitation alternatives, and decide if a detailed assessment is needed or not.

These objectives are achieved from the preliminary assessment as described in Fig. 5.5.

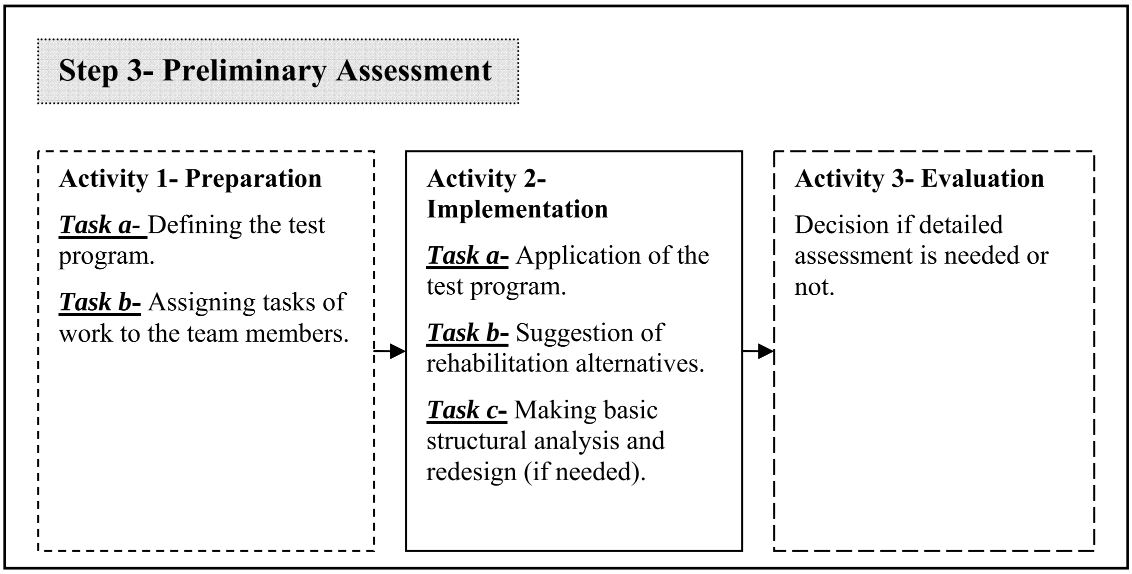


Fig. 5.5: Activities of the Preliminary Assessment.

Activity 1- Preparation

Preparation for the preliminary assessment includes the following tasks:

Task a- Defining the needed test program to compensate the missing information as determined in Step 2. In general a test program may includes exploratory removals to uncover some hidden objects, measurements of dimensions of some structural elements, non-destructive testing such as few rebound hammer tests, and cover meter tests in some locations to identify reinforcement. The purpose of such tests is to have information with acceptable level of accuracy about the structure to enable the structural capacity check, if needed. Sometimes no tests are needed in the preliminary assessment such as the cases in which adequate information about materials properties and sections detailing are available.

Task b- Assigning tasks of work to the team members- It is preferable at this time to start the assessment in parallel to save time. The task assignment may be in different forms according to the condition of the structure and the individual experiences of the team members. Such assignments include writing the report draft, making structural capacity checks, plotting plans, evaluation of test results, etc.

Activity 2- Implementation

Generally the main tasks to be involved during the preliminary assessment are:

<u>Task a-</u> Application of the test program- This can be done by local material testing laboratories as identified by the assessment team. Typical tests that can be made in this stage are: impact hammer test of concrete strength for various structural elements as needed, ultrasonic pulse velocity measurements, non-destructive detection of reinforcement steel using for example, micro cover meter, and taking possible samples for laboratory testing such as split concrete pieces or portions, reinforcing steel bars, or powder samples for chemical analysis. Results are reviewed by the team and conclusions about materials properties are made.

<u>Task b-</u> Suggestion of rehabilitation alternatives- The team who identified the problem causes and damage types and extents, sets few rehabilitation options appropriate to correct the situation. The alternatives are then evaluated by experience and preliminary cost analysis. The options are discussed with the owner to select a suitable rehabilitation option depending on the structural condition and availability of repair methods and techniques.

<u>Task c-</u> Making basic structural analysis and redesign- This is done in the cases that require structural capacity checks for some elements after assessment of sections, material properties, and rehabilitation option. The extent of such structural capacity check is limited to some calculations of loads, flexural capacity and shear strength of beams, or compressive strength of columns to assess the structural performance in current and/or future use, if any.

Activity 3- Evaluation

Decision if a detailed assessment is needed or not- The team has to decide this according to the results of the previous tasks. Some cases do not need detailed assessment such as the cases where at this level the structural condition is fully assessed and evaluated to be suitable for the intended use with the application of the suggested rehabilitation options. In cases where it is found that the structure as a whole or some of its parts are still in doubt regarding their structural capacity, further detailed assessment may be needed. Such cases can arise is some situations, for example, the cases where concrete compressive strength fails to meet the project requirements, and the preliminary structural capacity checks reveal that the structure or the elements under consideration fail to satisfy code requirements. In such cases a more detailed assessment step is to be followed to be certain that the situation is assessed to a higher degree of accuracy.

5.3.4 Step 4- Detailed Assessment

The detailed assessment is a process in which intensive efforts are made to get more precise information about the condition of the structure and the intervention action. Cases that require a detailed assessment are typically the cases that lack sufficient information to assess the building condition with confidence such as the cases of structural upgrading without the presence of sufficient structural details and material properties. This process is illustrated in Fig. 5.6.

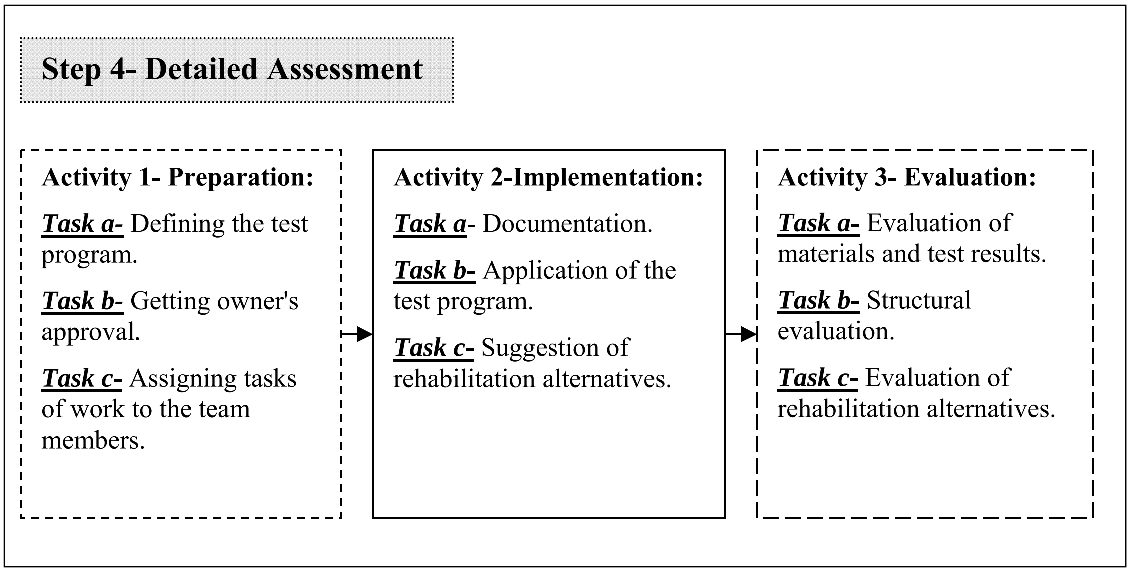


Fig. 5.6: Activities of the Detailed Assessment.

The detailed assessment comprises the following activities:

Activity 1- Preparation

The preparation for the detailed assessment considers three tasks as follows:

Task a- Defining the test program- The test program is one of the main features of the detailed assessment. Where testing is required, it is necessary to make an assessment of what specific information is needed, the purpose of each test and the information that it can provide. These have to be considered so that the appropriate tests are carried out. A testing program is usually required to give more precise information about several aspects regarding the condition of the structure. Generally the following are examples of such aspects:

i- Properties of the used building materials by testing representative and relatively large number of test samples.
ii- Excavation to foundation in order to determine foundation embedded depth, type, dimensions, concrete strength, and reinforcement.
iii- Surveying works to reproduce building drawings in the cases of no or insufficient structural details are available.
iv- Extent of deterioration in cases of reinforcement corrosion, for example testing to determine depth of carbonation, chlorides or sulfates, residual cross-section of reinforcement, etc.
v- Full load test for some parts of the structure where the material and sections information do not enable satisfactory structural capacity check.
vi- Soil bearing capacity in some cases.

Task b- Getting the owner's approval- Since the test program may be destructive for some parts, its cost may be relatively high, or special permits have to be obtained, the owner has to be informed about such issues in order to approve the assessment and its budget. A written agreement is preferable before starting the assessment.

Task c- Assigning tasks of work to the team members- As in the preliminary assessment, it is preferable at this time to start the assessment in parallel to save time. The task assignment may be in different forms according to the condition of the structure and the individual experiences of the team members. Such assignments include: writing the report draft, making structural analysis of the building, documentation, performing cost analysis of rehabilitation alternatives, evaluation of test results, etc. A time schedule of work can be prepared within this task.

Activity 2- Implementation

The implementation of the detailed assessment comprises the following tasks:

Task a- Documentation- Intensive effort should be exerted to locate, obtain, and review the pertinent documents relating to the structure. This is important to minimize the assumptions necessary to evaluate the structure. Typical information needed are related to design, materials, construction, service history, and repair history if any. Documents about such topics may be found at several institutions in Gaza Strip such as Municipalities, Ministry of Public Works and Housing, Association of Engineers, the project designer or sometimes the contractor. Contacting such institutions by visits, meetings, or communication tools may provide the team with valuable information that necessarily reduce the assessment efforts.

When the required documents are not available testing are usually required to compensate the missing information.

Task b- Application of the test program- Several activities and tests are to be performed by local material laboratories under supervision of the assessment team. More extensive sampling and testing is needed either to the whole structure or to selected parts for which the detailed assessment is made.

Task c- Suggestion of rehabilitation alternatives- All possible rehabilitation options that are appropriate to correct the problem have to be considered. Technical and financial analysis can be made for each alternative to serve as a basis for evaluation later on.

Activity 3- Evaluation

In general three tasks of evaluation are to be performed within the detailed assessment as follows:

Task a- Evaluation of materials and test results- Field and laboratory test results should be studied and evaluated to determine strength and quality of existing construction materials. For example when testing is performed for compressive strength of concrete, several types of tests may be performed such as impact hammer, ultrasound, and core tests. The results of these tests have to be correlated and evaluated by the assessment team to have the most reliable estimate of the in-situ concrete strength. Also tests for carbonation, chlorides, sulfates, etc, can be correlated to predict the variation of depth of influence of such chemical actions within the structure. Such evaluation enables the determination of locations that require repair, strengthening, or replacement.

Task b- Structural evaluation- Using the information obtained from the previous steps regarding dimension, geometry, and materials, the load-carrying capacity of the structure or portion under consideration can be determined. The choice of the evaluation method depends on factors such as the nature of the structure and the amount of information known. A common choice is evaluation by analysis, which is recommended when sufficient information are available. Also evaluation by analysis and load testing can be used in some situations where analytical methods give negative results or when the sections and the material characteristics of the structural elements cannot be determined.

Task c- Evaluation of rehabilitation alternatives- The suggested rehabilitation options have to be evaluated to select the optimum one. This can be done based on technical and cost considerations. Technical considerations are related to the repair materials availability, durability, and compatibility for original materials. Also they are related to the rehabilitation technique simplicity, practicality, and efficiency. On the other hand cost considerations include the direct cost of rehabilitation works, in addition to the indirect costs such as cost of closure of the building during rehabilitation.

Ranking for such factors is carried out by the assessment team according to the importance of the building, safety considerations, and owner's requirements in order to have an optimal option satisfying these considerations.

5.3.5 Step 5- Final Report

The final step of the assessment process is the assessment report. It has to reflect the efforts exerted by the assessment team, describe the condition of the structure in a professional and technical way and present documented information regarding the case. The entire investigation should be summarized in a comprehensive report describing the assessment method as a whole with sufficient description of all the findings including:

a. Purpose and scope of investigation.

b. Existing construction and documentation.
c. Field observations and condition survey.
d. Sampling and material testing.
e. Evaluation.
f. Findings and recommendations.

The recommended rehabilitation actions have to be fully described in the report with adequate details concerning the repair technique, needed materials, locations, construction details and drawings, etc.

Sometimes some protective measures to prevent or eliminate the occurrence of further damages or deteriorations should be addressed in the assessment report. This is to help building owners or users maintain the buildings in a proper way thus increasing their life span.

Also safety measures to be followed during preparation and implementation of rehabilitation works have to be pointed out.

5.4 CONCLUDED REMARKS

1. local conditions in Gaza Strip relating to rehabilitation of existing structures have been accounted for in the developed assessment approach as follows:

    a. Most of the projects in Gaza strip are of a small scale, therefore, can not bear expensive or extensive assessment procedures. For example, when steel corrosion is encountered it could be either limited in few locations that could be repaired easily, or propagated in many locations that could be demolished and replaced. There is no need to use advanced techniques that give information regarding corrosion rate, propagation, effect on structural capacity, and when to start repair as usually needed in large scale projects. The approach suggests a route suitable for each case of damage to reduce the assessment efforts and hence the cost of assessment. Excessive damages follow ***Route 1*** where no further assessment is needed. Minor defects are assessed in ***Route 2*** and only a minor survey is sufficient to identify the damage perfectly. Furthermore, moderate damages that need more assessment efforts are assessed by following ***Route 3*** in which the suggested assessment techniques are proportional to the value of the projects in Gaza Strip.

b. Most of the encountered damages in Gaza Strip are of minor or moderate nature such as dampness, hair cracks, and cracks in non-structural elements, etc. These damages require few efforts of assessment that are addressed in the developed assessment approach. Furthermore, when localized deteriorations are found rehabilitation techniques are adopted for remedy of the problem without the need of complicated testing and evaluation procedures.

c. Good quality building materials are generally in use in Gaza Strip. Only 6% of the damages were related to low strength concrete. This situation enabled the use of limited non-destructive testing that are sufficient to assess the structural capacity of the elements under consideration. The preliminary assessment step of the developed approach accounted for this situation and permitted the structural capacity checks based on such tests and available confidential information gathered during the assessment process.

d. The cost of the assessment is low since the approach orients the assessment engineers to a route proportional to the extent of damage from the first step without going into un-necessary details or investigations. This suits the economical situation in Gaza Strip.

e. In many assessments in Gaza Strip the experience of the assessment teams controlled the selection of rehabilitation options. To account for this inadequate practice, the approach suggests the selection of the intervention action based on comparative cost estimates for rehabilitation alternatives besides other technical aspects to repair the structure in an optimized way.

f. Several institutions with various expertise undertake assessments of existing structures in Gaza Strip. For this reason the developed assessment approach is not complicated and can be used for all assessment causes by any number of engineers with variable technical backgrounds but minimum experience that is certainly required.

2. The developed assessment approach which suits local conditions in Gaza Strip is suitable for other locations that are of similar conditions.

3. The practicality of developed assessment approach needs to be proven by verification of the approach with real case studies. This is made in the next chapter.

CHAPTER 6: VERIFICATION OF THE DEVELOPED ASSESSMENT APPROACH

6.1 INTRODUCTION:

In this chapter, nine case studies that have been previously assessed were selected for implementing the developed assessment approach. These cases were of different types of damages with varying degrees of sophistication and assessment efforts. The purpose of the implementation is to verify the suitability of the method for the prevailing conditions in Gaza Strip. The cases were selected to cover the most common requests for assessment and extents of damages that could be encountered in Gaza Strip. The selection has covered the following conditions:

1- Assessment of structural safety and capacity of buildings.
2- Assessment of buildings exposed to fire.
3- Assessment of buildings under construction after deficiency of concrete strength.
4- Assessment of buildings with minor defects.
5- Assessment of buildings with deteriorations.
6- Assessment of buildings after Israeli military attacks.

In the absence of a unified assessment approach, different assessment methods may be followed according to the background of the assessment teams, and this may result in different repair practice that may not be the optimal solution to the case or cases under consideration. The following examples are presented to support this opinion and to show the suitability of the developed assessment approach for conditions in Gaza Strip.

6.2 ASSESSMENT OF STRUCTURAL SAFETY AND CAPACITY OF BUILDINGS

Structural safety and capacity of buildings is one of the most common objectives of assessment and evaluation of existing structures. Sometimes damages appear in existing buildings to the extent that they can be noticed to the owners or to people living in the building. The assessment team has to study the case and suggest remedial actions to the problem.

6.2.1 Case Study No. (1-a): Assessment of a Four Floor Building

6.2.1.1 General Description

The building was a mosque located at Al-Zaytoun area in Gaza city. It consisted of four floors: a ground floor and three typical floors. The building experienced a rotation towards the eastern and northern sides. The upper two floors were evacuated because of suspicions regarding the structural safety of the building which led to this assessment on the request of the owner (Ministry) in October 2002.

A team consisting of three engineers was engaged in this assessment to evaluate the structural safety of the building and give recommendations to overcome the problems.

6.2.1.2 Assessment Practice

The team performed the following practice to assess the building:

1- Site visit in October 2002.
2- Visual inspection and condition assessment on 18^{th} of December 2002.
3- Excavation to foundation and sampling on 20^{th} of December 2002.
4- Testing of soil, and concrete strength of structural elements.
5- Structural analysis and redesign.
6- Assessment report.

6.2.1.3 Application of the Developed Approach

The assessment method used coincides with the proposed assessment approach particularly with route No.3 as follows:

1- Site Visit: After studying the owner's request, a site visit was made to identify the case and predict the needed assessment efforts. Little information about the structure was available. There were no complete drawings, no quality control tests, the first two floors were constructed in 1970, the other two floors were added in 1994, and the upper two floors were evacuated after the recognition of the problem. Hence, it was judged by the assessment team that the detected damages needed detailed assessment with a test program. A technical and financial proposal was made to get the owner's approval.

2- *Condition Survey*: Visual inspection and condition assessment of the building were made containing the following tasks:

a. Description of the building and its location.
b. Surveying works to reproduce the building plans.
c. Measurements of structural elements such as columns, beams, and slabs with the determination of columns reinforcement.
d. Verification of the as-built construction to the available drawings.
e. Identification of various damages in the building.
f. Measurement of the building displacement at the roof level to both the eastern and northern sides.

3- *Detailed Assessment*: It was assessed that the main damage was the tilting of the building. The assessment team concluded that this situation was related foundation settlement, so they decided to continue with a detailed assessment having a test program as follows:

a- Excavation to foundation to measure foundation depth, thickness, and concrete compressive strength.
b- Soil sampling and testing assess the soil bearing capacity.
c- Testing compressive strength of concrete for columns, ground beams, and slab beams using the impact hammer.

By structural assessment and analysis of the mat foundation, it was verified that stresses were not uniformly distributed to the soil due to the geometrical eccentricity of the building. This resulted in excess stresses at the eastern and northern sides than the allowable soil bearing capacity, the matter that caused soil settlement at these locations. As a result tilting of the structure occurred. Also it was verified that the columns dimensions, reinforcement, and concrete strength made the section unsafe under existing loads.

The solution was to reduce the building loads by removal of a floor or more. By analysis and re-design, removal of the upper two floors was sufficient to prevent excess soil pressure and verify the safety of the building.

4- *Assessment Report*: The team issued a comprehensive assessment report describing the case with the following headings:

Background; General description; Testing program; Test results; Structural condition of the building; Structural study; Solution; and Recommendations.

Also it contained an appendix with the building plans, photographs of the damages, and the testing reports.

6.2.1.4 Comments

The implemented assessment method conformed to the developed approach. The results reached were satisfactory and scientifically proven.

6.2.2 Case Study No. (1-b): Assessment of a Seven Floors Building

6.2.2.1 General Description

The building was located at Dir Al-Latin Street, Al-Zaytoun area in Gaza city. It consisted of a ground floor with a mezzanine and six typical floors. The building was under finishing works at the time of assessment in August and September 2000. The request for assessment was inquired by the owner (private company).

Visual inspection of the building dated on 30/08/2000 showed that there were no defects or cracks in the building except a non-uniform vertical separation between the building and the adjacent one in the eastern side in addition to dampness in the ground floor due rain water penetrating through this separation.

The team monitored this separation for five days using the required engineering markings to monitor building movement in all directions, and concluded that the structure was un-stable. Settlement of the building caused it's tilting towards the eastern and southern sides. Since it was judged that the situation is dangerous and needed immediate intervention action, the team recommended the followings:

1- Preventing further movement of the building by use of a special supporting structural system consisting of piles, a continuous pile cap, and supporting columns as shown in Figs 6.1 and 6.2.

2- Removing the unlicensed floors (the upper four floors) immediately.

3- Performing a detailed test program including: soil test, exploration of foundations, and testing of the used building materials.

4- Making a structural study to check the structural capacity of the building.

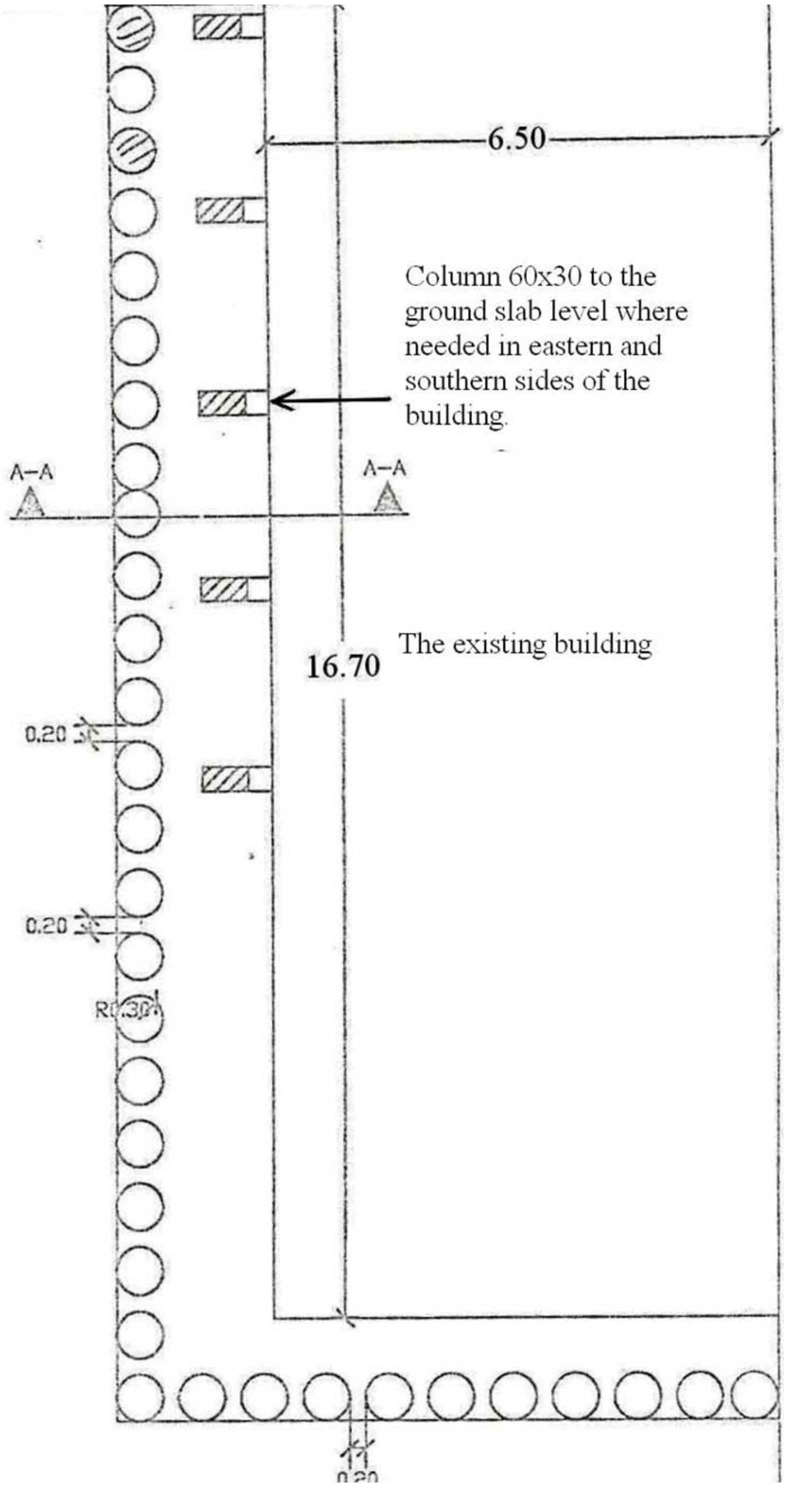


Fig. 6.1: Supporting System Plan (Case 1-b).

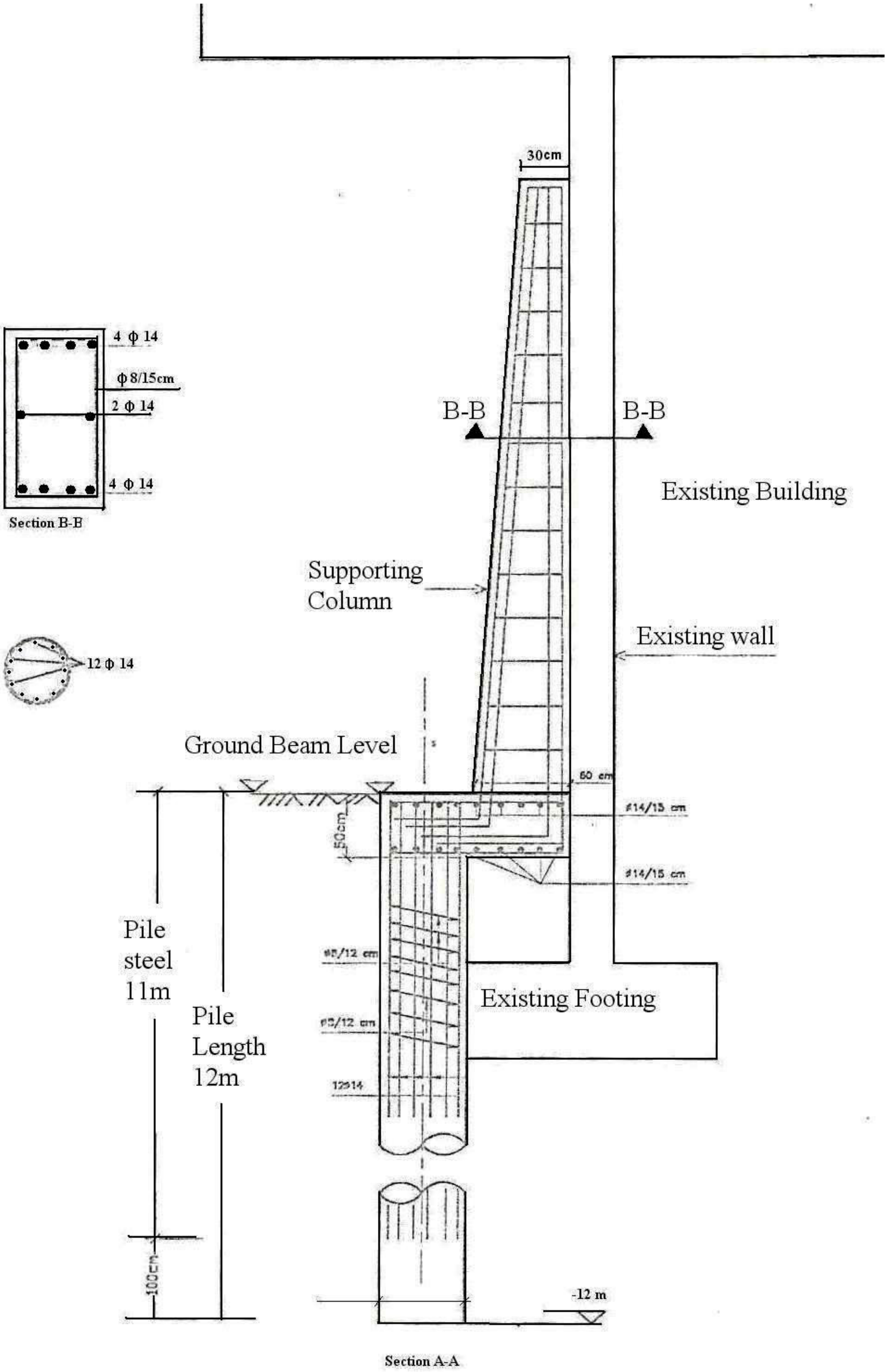


Fig. 6.2: Supporting System Sections (Case 1-b).

6.2.2.2 Assessment Practice

The team performed the following steps of assessment:

1- A site visit and visual inspection on 30/08/2000.

2- Monitoring of the markings to joint separation for five days from 01/09/2000 to 05/09/2000.

6.2.2.3 Application of the Developed Approach

Clearly from the preceding description it can be noticed that the team recommendations were based on their impression about the case from the site visit. They concluded that the building was unsafe and needed a supporting system as an immediate safety measure. The next step was the removal of four floors. Then recommendations for a further investigation to study the case were given.

In application of the developed approach to this case the following steps should have been performed:

1- *Site visit:* After receiving the owner's request a site visit was made to get possible information and identify the building condition. The report revealed that there were no structural drawings available and no cracks or defects in the building structural members were noticed. The major problem was represented by a vertical separation between the building and the adjacent one which probably happened due to settlement of the building as a result of excess loading and additional floors, or due to soil settlement as a result of water penetration through the joint separation. For this case, testing and measurements had to be made to identify the real cause of the problem. So the appropriate route in the approach is Route No. 3.

2- *Condition survey:* This process is needed to identify and locate the damages. Measurements had to be made to the separation and settlements that occurred in the building. Unfortunately, the report mentioned nothing about this issue, and even when monitoring of the separation was mentioned, no information about the dimensions or the rate of movement was declared.

3- *Detailed assessment:* Since the amount of available information was insufficient to identify the real cause of the problem or enable structural capacity checks with confidence, a detailed assessment with a predefined testing program was needed. Particularly the following tasks had to be performed:

   a- Excavation to foundation to measure foundation depth, dimensions, and concrete compressive strength.
   b- Soil investigation to determine its characteristics and bearing capacity.
   c- Surveying works to verify the as-built construction with the available drawings and to identify dimensions of the structural members.
   d- Testing of the building materials used in the building mainly concrete and reinforcement.
   e- Detecting the used reinforcement in various structural members especially columns.
   f- Performing structural analysis and redesign based on the available information and load conditions.
   g- Assessing the situation and giving rehabilitation alternatives.
   h- Recommending optimum repair options suitable for solving the problem.

4- *Assessment report:* Which had to be comprehensive and perfectly describe the assessment process.

6.2.2.4 Comments

This case represents an example of cases performed by experience of the assessment team although a technical assessment process if used might have led to different results. The adopted solution was not technically verified. For example no answers were found to the following questions:

1- What were the causes that led to the recommendation of the supporting system?
2- What were the structural considerations in designing such system?
3- What were the structural considerations for recommending removal of the upper four floors?

4- If the indicated floors were removed, what was the need for the supporting system?

5- What was the need for a detailed test program after supporting the building and removal of excess loads?

All these questions had to be declared in the assessment report; otherwise such recommendations seem to be punishment to the owner for building without a permit rather than a technical solution for an existing problem.

6.3 ASSESSMENT OF BUILDINGS EXPOSED TO FIRE

Many cases for assessment of buildings after fire were included in the case studies survey. The following were selected for application of the assessment approach where different extents of damage were encountered. The cases required different assessment efforts.

6.3.1 Case No. (2-a): A Case with Moderate Damages

6.3.1.1 General Description

This case was concerned in assessment of damages that occurred in a building exposed to fire in its ground floor for about four hours. The building was located in Al-Daraj area. It consisted of two floors, the ground floor was used as stores, and the first floor contained two residential apartments. During the night of 01/06/1997 a large fire broke out in the western part of the ground floor. It lasted from 23:15 to 3:00 am. The stored materials that were burned comprised easily combustible materials such as large amounts of plastic shoes, photocopying papers, copybooks, and bags of lentils.

The owner requested the assessment on 08/06/1997, and two engineers were assigned to assess the building and give their recommendations.

After a site visit and visual inspection the team assessed the case as follows:

1- Since the stored materials were easily combustible and the fire continued for about four hours, the concrete and reinforcement lost most of their resistance.

2- Since flames were directed upward, the upper parts of the ground floor were directly affected more than other parts. This was represented in spalling of plaster layers from the upper 1.5m of the columns, appearance of cracks in some columns, and spalling of plaster from walls. Also the slab was more affected and the damages comprised spalling of plaster, cracking and spalling of concrete cover in some locations, falling of some slab concrete blocks, disintegration of concrete, and reinforcement bars cut off in some slab ribs.

3- Although these damages occurred, the building was in a condition that can be restored to its initial state by repair and rehabilitation.

To repair the damages, the team recommended the following: (numbers and letters refer to locations shown in sketches attached with the assessment report and reproduced in Fig. 6.3):

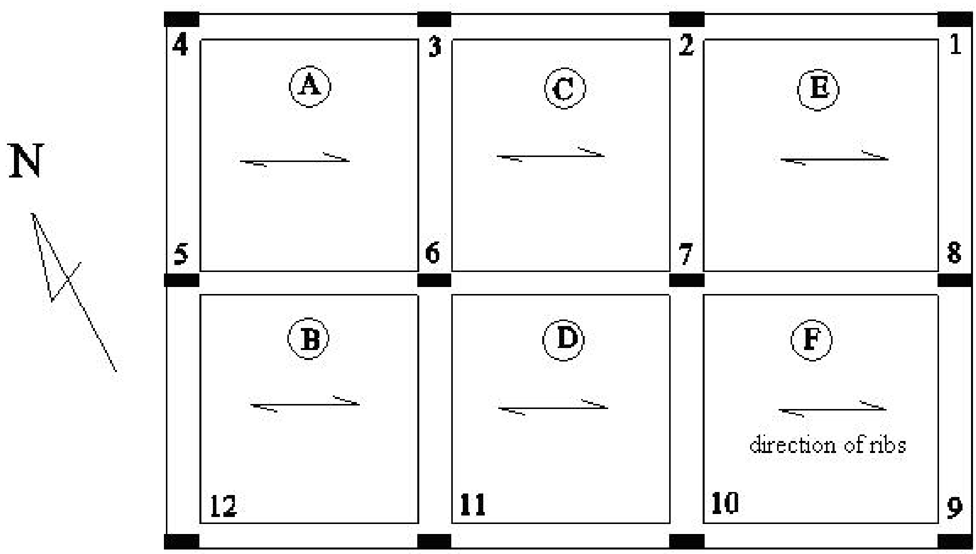


Fig. 6.3: Slab Reinforcement Plan (Case 2-a).

1- Strengthening of columns (2-6-7-10-11) by jacketing according to technical methods and a high level of engineering supervision.

2- Recasting and strengthening of slab beams between columns (2-7-10) and (6-11) according to technical methods and a high level of engineering supervision.

3- Reconstructing parts (B, D, E, and F) of the ground floor slab according to technical methods and a high level of engineering supervision.

4- Reconstructing the concrete cover to the slab ribs in parts (A, C) and the beam connecting the columns (5-6-7-8).

5- Re-plastering the walls and the slab.

6- Re-painting the external elevations of the first floor.

6.3.1.2 Assessment Practice

The assessment practice involved by the assessment team comprised the following steps:

1- Site visit and visual inspection on 10/06/1997.
2- Assessment by experience.

There were no testing except some measurements during the site visit to locate the damages on available sketches of the plans and elevations.

6.3.1.3 Application of the Developed Approach

When applying the assessment approach on such a case, the following steps would have been involved:

1- Site visit: to take initial impression, meet concerned people who will give valuable information about the case, and to decide the required steps of assessment. During the site visit it was found that:

a- Fire duration was about 4 hours.
b- The burned materials were easily combustible.
c- Damages were in the upper parts of the columns and in the ground floor slab.
d- There were no structural drawings.

At this stage, the assessment team could conclude that:

a- The extent and severity of damages need assessment and are of the type that can be rehabilitated.
b- The appropriate route in the developed approach is Route No. 3.
c- The situation needs a preliminary assessment to evaluate the effect of fire on the structural capacity of columns and slabs.
d- Based on this assessment the team can make preliminary prediction of the cost of assessment.

2- *Condition survey:* to identify, measure, and locate the damages in a way that facilitates grouping and classification of damages into groups of similar nature. The following damages were found:

a. Spalling of plaster layers from the upper 1.5m of the columns.
b. Appearance of cracks in some columns.
c. Spalling of plaster from walls.
d. Spalling of ground floor slab plaster layer.
e. Cracking and spalling of concrete cover in some locations of the slab.
f. Falling of some slab concrete blocks.
g. Disintegration of concrete and reinforcement bars cut off in some slab ribs.

Such damages and findings when evaluated by the assessment team can reveal that:

a- The type of burned materials and the fire duration might have caused loss of strength of concrete and reinforcement.
b- The reduction of the compressive strength of concrete and ductility of reinforcement had to be tested at selected locations.

This situation needs a preliminary assessment

3- *Preliminary assessment:* in which the following tasks had to be performed:

a- A test program to compensate the missing data needed for structural evaluation of the columns and slab such as:

   i- Non destructive testing or core test of concrete for columns and the ground floor slab.
   ii- Tests of samples of the cut reinforcement bars could be tested at laboratory for yield and ultimate stresses.
   iii-Measurement of columns cross-sections and number of reinforcement bars.

b- Preliminary structural analysis and redesign for columns and slab beams to evaluate their structural capacity and determine the needed rehabilitation or strengthening.

c- Selection of rehabilitation alternatives for columns and the slab.

d- Choosing the appropriate rehabilitation option based on preliminary cost assessment and availability of repair materials.

4- *Assessment report:* as a final step including all findings and recommendations.

6.3.1.4 Comments

This case study represents a case in which damages may affect the structural capacity of the structural elements considerably. Fire is a special case which reduces both the strength of concrete and the ductility of reinforcement based on several factors such as: the burned materials, the fire duration, and hence the predicted temperature during fire. The most appropriate method to identify such effect is testing of both concrete and reinforcement. This was not made or recommended by the assessment team.

Also in this case there were no structural drawings that provide sufficient details to perform a structural capacity check. For this reason the team had to make suitable measurements and testing to provide such information. On the other hand, the report recommended strengthening of some columns, reconstruction of some slab beams, and reconstruction of concrete cover to reinforcement of slab ribs. But in all recommendations, technical methods were not specified. The role of the assessment report is to provide adequate information a bout how to make the repair and what technique to use.

6.3.2 Case No. (2-b): A Case with Excessive Damages

6.3.2.1 General Description

This case is concerned in assessment and evaluation of a building that was located in Jabalia town and consisted of a ground floor of 340m^2 area. Although the building was exposed to fire on 26/09/1997, this assessment was requested in June, 2000. The cause of the delay is unknown.

A team consisting of two engineers made this assessment. They visited the site and found that the building was susceptible to collapse. So they recommended demolishing the existing superstructure to the ground beams level.

6.3.2.2 Assessment Practice

The assessment practice comprised the following tasks:

1- Revision of the available drawings.
2- Surveying works of the building.
3- Testing concrete.
4- Measurement of distortions.
5- Identification of the burned materials and assessment of temperature during fire.
6- Assessment report.

The report did not describe the assessment practice in detail. It only mentioned the headings without describing the assessment practice undergone by the team.

6.3.2.3 Application of the Developed Approach

This case is an example of cases where severe damages were detected and the rehabilitation was not feasible.

The developed assessment approach in this case suggests the following steps:

1- *Site visit:* During the site visit and by visual inspection it was found that:

a- The building was in a very bad condition represented by deteriorations of concrete and distortions of the structural elements such as the columns and the slab.

b- The damages reached almost every part of the building, the columns became out of their function and the slab was separated into several parts.

From the first impression it was concluded that rehabilitation of such damaged structure was economically not feasible. Hence the appropriate route in the developed assessment approach is Route No. 1, and the team recommended the demolition and rebuild of the superstructure.

2- *Assessment report:* in which the team described their findings and recommendations.

6.3.2.4 Comments

It could be found by inspection and team experience that rehabilitation is not feasible. Also extensive efforts and testing may be needed to identify the extent of damage while the expected results would be negative. The recommended action in such cases is to demolish. But this recommendation has to be explained in the assessment report by the following:

a- Verify that damages comprise the majority of the building by making some measurements to the damaged locations and estimating the percentage of damage.

b- Make rough cost estimate of the needed rehabilitation works and comparing it to the estimated cost of the rebuild option.

c- Describe why the rehabilitation is not feasible from both technical and economical points of view.

6.4 ASSESSMENT OF BUILDINGS UNDER CONSTRUCTION AFTER DEFICIENCY OF CONCRETE STRENGTH

Many cases of assessment of buildings in Gaza Strip were caused by concrete strength deficiency. Most of the cases were under construction or just after construction. Previous experience in such subject relates this problem to the failure of concrete samples when tested for compressive strength as part of the quality control process for ready mixed concrete. Usually when the owner discovers failure of test specimens to satisfy the required concrete grade, he requests an assessment of structural safety of his building and asks for an engineering remedy of the problem.

6.4.1 Case No. (3): Assessment of Foundations Structural Capacity after Concrete Strength Failure

This case is an example of the cases in which concrete samples failed to satisfy the required compressive strength. The assessment was carried out in August, 2003 upon the request of both the owner of the building and the concrete production plant.

6.4.1.1 General Description

The building was located in Al-Maghazi area and was still under construction at the column necks stage. The problem was noticed when the test results of concrete cube samples failed to satisfy the specified compressive strength as tested after seven days. Within this period column necks were constructed, but the work was stopped at this stage until 28 days test results appeared. Since the results were unsatisfactory, four core samples were tested by a local material testing laboratory and the results were also unsatisfactory. Furthermore, ten core samples were tested by another materials testing laboratory and most of the results didn't meet the required compressive strength.

The assessment was requested to evaluate the concrete strength and assess the structural capacity of the foundations.

6.4.1.2 Assessment Practice

A team consisting of three engineers carried out this assessment and performed the following tasks:

a- A site visit to identify the structural condition of the building.

b- A study of the available information such as the building drawing and concrete test results.

c- An additional test program of the concrete strength was performed by core test and impact hammer test.

d- Structural analysis and redesign of the foundation was carried out based on the actual concrete compressive strength and footings dimensions.

e- Final recommendations regarding the structural capacity and safety were given.

It was found that the compressive strength of concrete in foundations failed to satisfy the specified compressive strength and about 78% of the footings were under capacity of carrying the design loads. The team recommended demolition and rebuild of the building.

6.4.1.3 Application of the Developed Approach

Such cases require Route No. 3 with a preliminary or a detailed assessment to evaluate the compressive strength (usually by testing) and assess the structural capacity of elements under consideration (usually by structural analysis and redesign).

In particular the following steps should have been made:

1- Site visit: During the site visit and by visual inspection it was found that:

a. The building was under construction in the stage of column necks.

b. Available test results showed that the required concrete compressive strength was not satisfied in many locations.

c. A concrete portion that was easily separated from a footing top corner by a hammer showed uneven distribution of aggregates in the concrete, and gave an indication of concrete weakness.

Although the compressive strength of concrete was tested previously by cores in some locations, a judgment of the actual compressive strength was still needed to evaluate the in-situ compressive strength of concrete in each footing to allow accurate assessment of footings structural capacity. This can be made by following Route No.3.

2- *Condition survey:* which include measurements of existing footings dimensions to be verified with the structural drawings, revision of available test results, and determination of the needed missing information.

It was found that:

a- The footings dimensions and locations are the same as in the drawings.

b- Test results varied considerably from a location to another.

This variation of test results made it necessary to have a better estimate of concrete compressive strength in every footing by additional testing. So a preliminary assessment is suggested.

3- *Preliminary assessment:* in which the following tasks were applied:

a. A test program including additional core samples of some locations with impact hammer testing of all locations.

b. Correlating hammer results to the core results in order to predict the in-situ compressive strength in all footings to a good degree of accuracy.

c. Assessment of loads on the foundations according to the drawings and design number of floors.

d. Assessment of the structural safety of the footing by redesign.

The result of assessment showed that 78% of the footings cannot safely support design loads. So the following alternatives to solve the problem can be compared:

a- Reduction of the applied loads, by using lighter concrete blocks and covering materials, or reduction of the design number of floors.
b- Strengthening of the footings to be able to carry the applied loads.
c- Demolishing and reconstructing the faulty footings.

Among these options, the third option was selected, but for a practical point of view, it was decided to demolish and reconstruct all the footings.

4- *Assessment report:* including the findings and recommendations was prepared.

6.4.1.4 Comments

The decision of demolish and rebuild was taken in this case considering the following criteria which may be found in many similar cases:

a- The building was in its initial construction stage, so the cost of demolish and rebuild is relatively small and the cost of the other alternatives may be larger or comparative to this cost.

b- Although some footings were initially over designed and a good factor of safety was still available on structural capacity aspects, the durability of concrete may be proportionally decreased with the reduction of concrete strength since other properties also change such as permeability, bond strength, and elastic modulus. This reduction supports the decision of demolish and rebuild, or at least necessitates the use of additional protection against water penetration.

c- Practical considerations have to be considered while preparing the assessment recommendations. So in this case all the footings were demolished while their concrete strength was still satisfactory and safe.

6.5 ASSESSMENT OF BUILDINGS WITH MINOR DEFECTS

When minor defects are encountered in a building, the decision can readily be taken to repair these defects. But the most important is to identify the real causes of the defects in order to solve the problem completely; otherwise the repair will not last for a long time and the same problem will come back again.

The following case is an example of minor defects that could be encountered in buildings in Gaza Strip as a result of poor construction practice or inadequate engineering supervision.

6.5.1 Case No. (4): Assessment of a New Building with Minor Defects

This case was concerned in studying some defects and construction errors in a university building in Beit Lahia upon the request of the University Chairman in January, 2007.

6.5.1.1 General Description

The building consisted of three floors, a basement, aground, and a first floor. The scope of the assessment was to evaluate and recommend technical solutions to the defects that were noticed in the building after adding the first floor during the year 2006.

6.5.1.2 Assessment Practice

A team consisting of two engineers carried out this assessment and performed the following tasks:

a- A site visit to identify the condition of the building on 11/01/2007.

b- A study of the available drawing and contract documents to identify the project specifications.

c- A condition survey to identify and locate the defects on 17/01/2007.

d- Final report and recommendations.

It was found that the majority of defects were caused by water penetration through the expansion joint between the building eastern and middle parts. Also dampness appeared in different locations of the building due to defects in the external plastering and drainage system. In addition, horizontal and crazy cracks were found in some locations.

6.5.1.3 Application of the Developed Approach

The case under consideration requires Route No. 2 as the encountered defects were minor. A minor survey is needed to identify the defects and find the real causes of the problem. The following steps would be made:

1- *Site visit:* During the site visit and by visual inspection it was found that:

   a. Dampness appeared in several locations of the building especially at the eastern expansion joint.
   b. Dampness was noticed in the external wall of the computer lab in the first floor and was caused by water penetration through cracks in the external plaster of the southern wall.
   c. Horizontal cracks appeared in the external face between concrete blocks and concrete lintels in the southern wall, in addition to longitudinal cracks in the slab plaster at the eastern expansion joint.

   These defects were minor and could be repaired after determination of their real causes. The appropriate route is Route No. 2.

2- *Minor Survey:* including identifying defects locations and exploring their causes. Tiles at the terrace near the computer lab external wall, external plaster layer in some locations of the wall, and the isolation layer of the expansion joint at the roof were explored. It was found that:

   a- The horizontal cracks in the external wall at a computer lab in the first floor were caused by errors in construction. They were in the form of horizontal cracks between concrete blocks and the reinforced concrete lintels. By removal of the plaster it was revealed that a space of about 8 to 10cm between block and concrete was filled using mortar, some pieces of concrete block, and tiles etc. There was no wire mesh used under the plaster. The mortar settled and cracks appeared the matter that led to water penetration to the inner side.

   b- Although a bituminous isolation layer was made under the terrace tiles, this layer was not properly applied, and caused the penetration of water to the ground floor slab.

c- The isolation of the parapet wall of the expansion joint in the roof was not carried out in a proper way and didn't comply with the project specifications. So it wasn't effective and permitted penetration of water through the joint. In addition, a PVC sleeve passing through the parapet wall was fractured due to differential settlement of the building at the joint and was not closed from both ends which permitted water to penetrate through the pipe into the joint.

Once the causes of the problem were identified, technical methods to repair the defects could be described.

3- *Assessment report:* including the findings and recommendations was prepared.

6.5.1.4 Comments

The appearance of such defects in buildings is noticed in many cases. Sometimes the assessment engineers did not pay attention to minor defects especially in the cases of other structural damages. As can be seen in this case, the defect causes needed a minor exploratory survey to be identified. This should be done in all cases where such minor defects are encountered.

6.6 ASSESSMENT OF BUILDINGS WITH DETERIORATIONS

Deterioration of reinforced concrete was encountered in some buildings in Gaza Strip. Most of these buildings were constructed before 1970's. Neglect, dampness, environmental conditions, and probably the construction materials played an important role in such damages. Before trying repair of deteriorated reinforced concrete members, good assessment is necessary to identify the causes of deterioration. Testing is highly recommended in such cases.

The following case is an example of buildings in which deteriorations reached an advanced situation such that removal of the damaged locations was found the most appropriate remedy.

6.6.1 Case No. (5): A Structural Assessment of a Mosque in Gaza

This case was concerned in assessment of the structural condition of a mosque in Gaza city after appearance of cracks and damages in the old part of the mosque. The study was performed in April, 2001 on the request of the owner (Ministry).

6.6.1.1 General Description

The building was located in Al-Sabra. It consisted of two parts. The old part was constructed in 1962 and contained the mosque hall, the dome, the toilet block, and a grave room located in the northern eastern corner. The other part was an extension constructed in 1988 and consisted of two reinforced concrete floors and a third floor sheeted with tin board. No drawings were available. A sketch of the Ground floor plan (old part) is shown in Fig. 6.4.

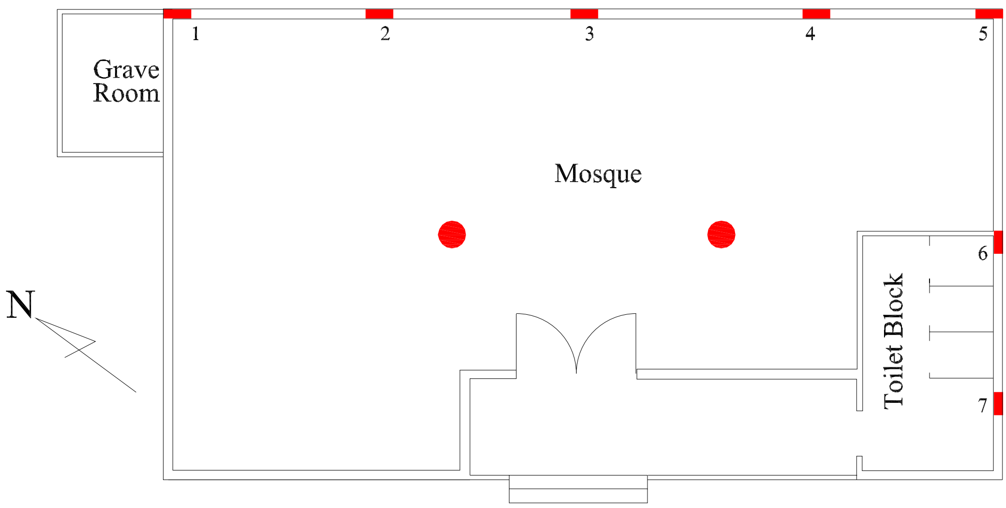


Fig. 6.4: Old Part Ground Floor Plan (Case 5).

6.6.1.2 Assessment Practice

A team consisting of five engineers carried out this assessment and performed the following tasks:

a- A site visit to identify the condition of the building on 15/04/2001.
b- Surveying works to reproduce architectural drawings of the building.
c- Final report and recommendations.

6.6.1.3 Application of the Developed Approach

1- *Site visit:* During the site visit and by visual inspection it was found that damages were located mainly in the old part of the building, and appeared in the form of cracks in columns, walls, and toilet block slab. Concrete was disintegrated in some locations, and reinforcement bars were corroded.

These damages were of a structural nature and had to be more identified to find out their real causes. The appropriate route is Route No. 3.

2- *Condition survey:* including the identification of defects locations and exploring their causes. It was found that:

a. The eastern wall columns (1, 2, 3 and 4) experienced transverse and longitudinal cracks, spalling of concrete cover, and appearance of reinforcing bars.

b. Columns of the southern side (6 and 7) had vertical cracks and fracture of their ceramic tiles.

c. The southern eastern corner column (5) had vertical cracks and disintegration of its concrete.

d. Toilets slab was deflected and cracked. It was noticed that shoring by steel pipes was used to support this slab.

e. Walls of the toilet block experienced horizontal and inclined cracks.

f. The eastern wall of the mosque had horizontal and inclined cracks in addition to disintegration of the concrete of lintels.

g. The eastern and northern walls of the grave room were largely cracked.

Although the nature of these damages convinced the assessment team that removal of deteriorated members was the best solution, an assessment with a testing program to identify the causes of the problem and the structural capacity of the building was needed. So the following step is the either preliminary or detailed assessment.

3- *Preliminary assessment:* in which the following tasks had to be performed:

a- A test program to compensate the missing data needed for structural evaluation of the building such as:

i. Non destructive testing or core test of concrete for columns.
ii. Tests of samples of the cut reinforcement bars.
iii. Measurement of columns cross-sections and number of reinforcement bars.
iv. Excavation to foundation to identify their condition and materials properties.
v. Chemical tests to powder samples to check the presence of chlorides or sulfates in the original concrete.

b- Preliminary structural analysis and redesign for columns and foundations to evaluate their structural capacity and determine the needed rehabilitation or strengthening.

c- Selection of rehabilitation alternatives for columns and the slab.

d- Choosing the appropriate rehabilitation option based on preliminary cost assessment and availability of repair materials.

The assessment team related the problem to the following causes:

a. Weakness of concrete used in columns and its high permeability enabled moisture penetration into the concrete and caused steel corrosion that correspondingly caused cracking of concrete cover and reduction of the load carrying capacity of the columns.

b. The same was applicable to the toilet block where deflection and cracks occurred in the slab making it unable to resist the applied loads.

c. The absence of a proper drainage system caused dampness in the slab.

Once the causes of the problem were identified, technical methods to repair the defects could be described.

4- *Assessment report:* including the findings and recommendations is prepared. The following recommendation would have set out:

a. Removal and reconstruction of the eastern side columns.
b. Removal and reconstruction of the southern eastern corner column.
c. Removal of the room constructed in the first floor on top of the toilet block.
d. Removal and reconstruction of the toilet block slab.
e. Strengthening by jacketing of the southern side columns.
f. Repair of toilet block walls.

It should be mentioned that detailed methods for repair and strengthening were described in the assessment report.

6.6.1.4 Comments

This case was assessed mainly be experience of the assessment team. Damaged locations were recommended to be removed and reconstructed. But nothing was mentioned about the following:

a. The used foundation system, dimensions, or material properties.
b. Structural analysis and design calculations for the building structural capacity.
c. The soil type, bearing capacity and the probability of settlements that might contributed to the causes of the cracks especially the horizontal cracks in the walls and columns.
d. The presence of sulfates, chlorides or other deleterious substances in the concrete used in columns or slabs.

It should be mentioned that the mosque was completely demolished and reconstructed with a new design and better use of the land.

6.7 ASSESSMENT OF BUILDINGS AFTER ISRAELI MILITARY ATTACKS

For its particular situation, many buildings in Gaza Strip were susceptible to various attacks by the Israeli army represented in different types of destructive weapons that caused total or partial destructions. Direct incurrence of buildings by destructive missiles causes damages to these buildings. Although the main cause of damages is usually understood, other defects or damages might have occurred before the explosion, and their causes need to be assessed as well.

In general, buildings in Gaza strip are very close or even attached to each other. This situation makes the destructive actions effective not only at the explosion location but also in the neighborhood buildings as well. Demolition and rebuild of every damaged location is not practical or economical solution. So rehabilitation is preferred wherever possible.

6.7.1 Case No. (6-a): Assessment of a Three Floors Building after Destruction of an Adjacent Building

This case was carried out in May, 2001 for a building located in Omar El-Mokhtar Street. The building was adjacent to a building that was incurred by Israeli missiles on 30/04/2001.

6.7.1.1 General Description

The building was about 190m^2 plan and consisted of three floors, a ground and two upper floors. About 160m^2 of the ground floor were constructed in 1971. The ground floor extension and the upper two floors were constructed in 1995. No drawings were available, but a certificate of structural capacity of the building signed by a structural engineer was available.

The explosion that occurred in the eastern side adjacent building caused severe damages to the eastern ground floor columns of the building. They were largely buckled and fractured, the wall was completely destroyed, and some hair cracks occurred in the wall of the upper floor. Fortunately the building did not experience other damages and remained stable. The owner shored the ground floor slab at the damaged locations by steel pipes.

6.7.1.2 Assessment Practice

A team consisting of two engineers carried out this assessment and performed the following tasks:

a- A site visit and visual inspection to identify the condition of the building on 06/05/2001.

b- Final report and recommendations.

6.7.1.3 *Application of the Developed Approach*

1. *Site visit:* During the site visit and by visual inspection it was found that damages were located mainly at the eastern side columns of the ground floor. Three columns showed severe damages and required demolition and rebuild. All other locations were safe and had no damage. The original structural capacity of the building was ensured by a structural capacity certificate.

   In this case the appropriate route is Route No. 1 where no additional assessment steps are required

2. *Assessment report:* that included the recommendations of demolition and rebuild of the damaged columns.

   Technical methods of demolition and reconstruction were described in the assessment report.

6.7.1.4 *Comments*

Gaza strip buildings are generally very close to each other. This situation increases the probability of occurrence of damages not only in the targeted buildings but also in the neighborhoods. In most of the cases damages spread out in the buildings enclosed by a circle of a variable diameter according to the intensity of the explosion. Also the detected damages vary in their extent according their closeness to the center of explosion and to the condition of the building itself. These damages range from totally destructed locations to minor damages in doors and windows. But in all cases all the damages should be described, quantified and assessed.

In rather old buildings, the assessment engineers have to differentiate between the locations that were in a good condition before the explosion and those that were initially in a bad condition. The assessment method should be appropriate for both conditions.

The structural condition of the building should be assessed after the explosion. It is advisable not to depend on previous structural capacity certificates only. Visual inspection and adequate assessment of main structural elements of the building are usually needed.

6.7.2 Case No. (6-b): Assessment of a Building after Being Shelled with a Missile

This case was carried out in April, 2001 for a building located in Tal- Elhawa area-Gaza and owned by a private company. A missile directly hit a staircase column in the fourth floor and caused its failure.

6.7.2.1 General Description

The building was about 570m^2 plan and consisted of eight floors, a ground and seven upper floors. It was recently constructed, some apartments were finished, and the others were still under finishing works.

The explosion occurred in the eastern side of the building and directly hit a staircase column in the fourth floor. The column was completely fractured and all the windows and doors in that floor were destroyed.

6.7.2.2 Assessment Practice

A team consisting of two engineers carried out this assessment and performed the following tasks:

a- A site visit and visual inspection to identify the condition of the building on 23/04/2001.

b- Final report and recommendations.

6.7.2.3 Application of the Developed Approach

1. *Site visit:* During the site visit and by visual inspection it was found that damages were local and limited to the damaged column that was directly hit. All the other structural parts were unaffected. Doors and windows of the fourth floor were destroyed.

   In this case the appropriate route is route No. 1 where no additional assessment steps are required

2. *Assessment report:* that included the recommendations of demolition and rebuild of the damaged column.

Technical methods of demolition and reconstruction were described in the assessment report.

6.7.2.4 Comments

The assessment of damages occurring due to destructive actions in many cases require less efforts of assessment especially in new buildings since the main cause of damage in readily identified. Normally complete destruction occurs to the directly hit locations. This destruction causes multiple damages to adjacent locations and the damage may reach progressive collapse of the whole structure in some cases depending on the building condition. In this case although the targeted location was a main structural member (column), the redistribution of loads after the column failure took place and the structure remained stable. This enabled the restoration of the building structural safety by replacement of the damaged location. It should be mentioned that the assessment team has to pay attention to study the structural stability after explosion and describe the rehabilitation method in detail taking into consideration all the necessary safety measures.

6.8 CONCLUDED REMARKS

It was demonstrated that the proposed assessment approach is applicable to a wide range of cases of damage in existing buildings in Gaza Strip. It was verified with a variety of case studies having different causes, types, and extent of damage.

The site visit was found essential to define the route of assessment. Such routes when followed provide planned regime of inspection and assessment that enables the identification of the problem, discover its causes, and select the appropriate intervention action. The approach provides a clear guide to assessment practice. The selection of routes is based on the damages detected during the site visit. Cases with excessive damages could be directed to Route No.1 of the developed assessment approach without the need for additional steps. Minor defects when encountered need Route No. 2. Moderate damages could be adequately assessed in Route No. 3.

In some cases, the developed assessment approach if followed would result in the same results as previously assessed cases. But in the other cases local assessment practice have shown unsatisfactory results. The approach would give more rational and economical results.

The suitability of the developed assessment approach is not limited to Gaza Strip conditions only, but is suitable for other locations having the same circumstances as well.

To enable the use of the developed approach at practical level, an Assessment Manual is prepared and attached in annex A. This Manual gives a description of the developed assessment approach main features, components, applicability, and use, in addition, to useful information regarding damage types and related rehabilitation techniques.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

1- The proposed assessment approach has been developed to assist local engineers in planning and implementing assessment of existing structures in a uniform way taking into consideration the rehabilitation needs and the prevailing conditions in Gaza Strip. The approach consists of three alternative routes depending on the extent of damage. ***Route 1:*** Excessive Damage, ***Route 2:*** Minor Defects and ***Route 3:*** Moderate Damage. The routes consist of steps having several activities which have several tasks. The steps are designed to be planned, implemented, and evaluated at each assessment stage. This is to minimize the assessment efforts and consequently the cost of assessment, in addition to adequately assess the condition of the structure and recommend the appropriate intervention action. The approach is simple, cost effective, and has no limitations regarding the number of the assessment team members or their technical backgrounds. It has the following characteristics:

   a. The approach is cost effective since it orients the assessment engineers to a route proportional to the extent of damage from the first step without going into un-necessary details or investigations.

   b. It guarantees the efficient assessment of damages and defects since all of its steps need planning and preparation before implementation. This enables the judgment of why, how, and when to do an activity in order to only perform the necessary tasks that lead to reasonable prognosis of the cause of damage and its identification.

   c. The approach suggests the selection of the intervention action based on comparative cost estimates for rehabilitation alternatives besides other technical aspects to repair the structure in an optimized way.

   d. The approach is not complicated and can be used for all assessment causes by any number of rehabilitation engineers with variable technical backgrounds but minimum experience that is certainly required.

2- The developed assessment approach can be used effectively in Gaza Strip. For the following reasons:

   a. Most of the projects in Gaza Strip are of a small scale, therefore, can not bear expensive or extensive assessment procedures. For example, when steel corrosion is encountered it could be either limited in few locations that could be repaired easily, or propagated in many locations that could be demolished and replaced. There is no need to use advanced techniques that give information regarding corrosion rate, propagation, effect on structural capacity, and when to start repair as usually needed in large scale projects.

   b. Most of the encountered damages in the case studies are of moderate nature such as dampness, hair cracks, and cracks in non-structural elements, etc. These damages require few efforts of assessment that are addressed in the developed assessment approach.

   c. Good quality building materials are generally used. Only 6% of the damages in the case studies survey were related to low strength concrete. This situation enabled the use of non-destructive concrete testing that was sufficient to assess the structural capacity of the elements under consideration.

3- It is believed that the developed assessment approach can be applied in the West Bank after some modification (if needed) related to type of construction materials, climatic conditions, etc. Also it can be applied to other countries with similar situations.

4- The developed assessment approach when applied to pre-assessed case studies in Gaza Strip has showed that different results would be expected. In many cases it would give more rational and economical solutions than those adopted in the previous assessments.

5- The efforts associated with many of the international assessment approaches generally exceed those needed by the expected cases in Gaza Strip. For example, no aggregate silica reactions or frost actions were reported in case studies, in addition to the small scale rehabilitation projects that were found.

6- The local assessment practice in Gaza Strip has the following limitations:

a. Some cases are assessed based on team experience only while the situation requires more in depth investigations.
b. Technical reports prepared by the assessment teams were in most cases inadequate. Some of the assessment reports consisted of not more than one or two pages, and gave a general description of the team observations. They did not give proper identification of damage in a technical way, ignored essential information regarding the cases under consideration, and missed the detailed description of repair techniques for the encountered damages. This led to misunderstanding the problem and reduced the technical value of such reports.
c. Limited concrete testing was used although accurate assessments usually need various types of tests for proper identification of damages in existing structures.
d. Various assessment practices were used and no unified assessment method was followed by the assessment engineers.

For these reasons local assessment practice needs to be modified, upgraded, and unified.

7- Almost in all the cases, the rehabilitation process in local assessment practice ended at the stage of recommendation of an intervention action with no emphasis on the necessity to complete the repair under supervision of the assessment team. This situation needs to be further evaluated and discussed since the assessment team is more capable of performing the job than others who were not involved in the assessment.

8- The buildings in Gaza Strip where damages occurred have been either private residential or public low rise buildings. The total value of such buildings and the state of damages limited the assessment methods to simple and preliminary investigations with few in-situ and laboratory tests mainly concerning concrete strength.

9- The existing buildings damages are of various causes, types, and extents that need to be properly assessed, identified, and repaired. More efforts are needed for adopting materials testing especially to determine the causes of deteriorations. The damages in existing building in Gaza Strip are related to one or more of the following causes:

a. Damages due to exposure conditions such as temperature, relative humidity, and concentration of salts in the atmosphere, were the reason of 49% of the assessment requests. Furthermore, these conditions played an important role in deterioration of concrete and hence corrosion of reinforcing steel that constituted 31% of the damages in the surveyed cases.

b. Damages due to construction errors, deficiency of concrete strength, and design faults were the reason of 28% of the assessment requests and caused about 27% of the damages in the surveyed cases.

c. Accidental events such as fire were the reason of 13% of the assessment requests and caused many damages in existing structures that comprised about 16% of the damages in the surveyed cases.

d. In addition, manmade destructions resulting from Israeli military invasions were important damage causes in existing buildings in Gaza Strip that resulted in completely or partially destroyed buildings the matter that added further complications and caused multiple types of destructions.

10. A comprehensive manual which has been prepared based on the developed approach will enable easier implementation by relevant local institutions and engineers.

7.2 RECOMMENDATIONS

1. It is recommended to use the proposed assessment approach for assessment and evaluation of existing structures in Gaza Strip, and study its applicability in the West Bank and other countries with similar situations. Local institutions and engineers are encouraged to use the prepared assessment manual.

2. Various institutions in Gaza Strip are encouraged to undertake professional training to some of their assessment members regarding the assessment, evaluation, and rehabilitation of structures.

3. Knowledge about this important topic is highly recommended to be included in local universities curriculums for Civil and Material Engineering Departments.

4. Further research on available repair materials and techniques is needed to recommend the most appropriate ones to the current situation in Gaza Strip.

5. Further research on causes of damages in Gaza Strip and remedial measured is recommended.

6. Further research is needed on mitigation measures related to existing types of damages in Gaza strip caused by design faults, construction errors, and maintenance practice.

REFERENCES

[1] Mohamed Ziara, **Urban Reconstruction**, N. Munier (ed.), Handbook on Urban Sustainability, PP 607-686. Published by Springer, 2007.

[2] C. Dave Gaughen, Joseph H. Brandon, **Overview Of Industry Guidance On Concrete Condition Assessment and Concrete Repair For Use Prior To Coating**, Special Publication SP-2085-SHR, NAVAL Facilities Engineering Service Center , Port Hueneme, California 93043-4370, June 2000.

[3] Mohamed Ziara, "**Structural Upgrading of RC Structures**", Seminar on rehabilitation of structures, Engineering Association, Gaza, Palestine, PP 78-110, 5-7 August, 2001.

[4] ICRI, International Concrete Repair Institute, **Concrete Repair Terminology**, http://www.icri.org, Visited on 20/7/2008, ConcreteRepairTerminology.pdf.

[5] Baldwin N.J.R, King E.S, **Field Studies Of The Effectiveness Of Concrete Repairs**, Phase1 Report: Desk study and literature review, Mott MacDonald Ltd for the Health and Safety Executive, Crown copyright 2003, First published 2003, ISBN 0 7176 2783 7.

[6] Sika, Construction Technology and Concepts Brochure, **Repair and Protection of Reinforced Concrete**, WP.07.04.3k, http://www.ribaproductselector.com, visited on 17/08/2008.

[7] Mohamed Ziara, **Strengthening of Structures**, ENGC 6355 Course, IUG, 2005.

[8] S.L Karunakaran, **Handbook on Repair and Rehabilitation of RC Buildings**, published by Director General (works), Central Public Works Department, Government of India, New Delhi, 2002.

[9] ACI 546R-04, American Concrete Institute, **Concrete Repair Guide**, Reported by ACI Committee 546, American Concrete Institute, MCP05.

[10] ISO-TC-71/SC-7/WG-2, International Organization of Standardization, **Maintenance and Repair of Concrete Structures – Part 2: Condition Assessment – Content and Execution**, Dated: 01/03/2007.

[11] The Concrete Repair Association (CRA), **The Route To A Successful Concrete Repair**, GN1, Reprint April 2001.

[12] SAMCO- Structural Assessment Monitoring and Control Network, **Guideline for the Assessment of Existing Structures,** Final Report 2006, F08a, Federal Institute of Materials Research and Testing (BAM), Division VII.2 Buildings and Structures, 12205 Berlin, Germany, web site http://www.samco.org

[13] CONTECVET, A Validated Users Manual for assessing the residual service life of concrete structures, **Manual for Assessing Corrosion-Affected Concrete Structures**, EC Innovation project IN30902I, Andrade, C., Rodriguez, J., 2000.

[14] CONTECVET, A Validated Users Manual for assessing the residual service life of concrete structures, **Manual for Assessing Concrete Structures Affected By Frost**, EC Innovation project IN30902I, Fagerlund,G., May 2001.

[15] CONTECVET, A Validated Users Manual for assessing the residual service life of concrete structures, **Leaching of Concrete**, EC Innovation project IN30902I, Fagerlund, G., Div. of Building Materials, Lund Inst. of Technology, Report TVBM-3091, 2000.

[16] NORECON, Network on Repair and Maintenance of Concrete Structures, Task T1: **Decisions and Requirements for Repair– A Review**, Edited by Jacob Mehus, NORECON, April 2004.

[17] NORECON, Network on Repair and Maintenance of Concrete Structures, Task T2: **Repair Methods- A Review**, Edited by Kajsa Byfors, NORECON, April 2004.

[18] NORECON, Network on Repair and Maintenance of Concrete Structures, Task T3: **Guidelines for Manufacturers, Contractors and Consultants on the Basis of European Standards**", Edited by Arne Damgaard Jensen, NORECON, April 2004.

[19] REHABCON Manual, **Strategy for Maintenance and Rehabilitation in Concrete Structures**, EC DG ENTR-C-2 Innovation and SME Programme, June 2004.

[20] BRIME, A Manual for Bridge Management in Europe, **A Project to Develop a Framework for a Bridge Management System for the European Road Network**, Final Report /D14/March 2001.

[21] ACI 201.1R-92 (Re-approved 1997), American Concrete Institute, **Guide for Making a Condition Survey of Concrete in Service**, reported by ACI Committee 201, American Concrete Institute, MCP05, 2005.

[22] ACI 364.1R-94 (Re-approved 1999), American Concrete Institute, **Guide for Evaluation of Concrete Structures Prior to Rehabilitation**, reported by ACI Committee 364, American Concrete Institute, MCP05, 2005.

[23] ACI 473 R-03, American Concrete Institute, **Strength Evaluation of Existing Concrete Buildings**, reported by ACI Committee 473, American Concrete Institute, MCP05, 2005.

[24] Raupach M., **Concrete Repair According to the New European Standard EN-1504**, Institut für Bauforschung RWTH Aachen, 2006.

[25] Davies Hywel, **European Standards for Repair and Protection of Concrete**, Hywel Davies Consultancy, May 2005.

[26] K. Soudki, **Concrete Problems and Repair Techniques**, a seminar held at Professional Engineers Association, Beirut, Lebanon, February, 2001.

[27] ACI 207.3R-94, American Concrete Institute, **Practices for Evaluation of Concrete in Existing Massive Structures for Service Conditions**", Reported by ACI Committee 207, American Concrete Institute, MCP05, 2005.

[28] EM 1110-2-2002, Department of the Army U.S., **Engineering and Design-Evaluation and Repair of Concrete Structures**, Army Corps of Engineers, 30/06/1995.

[29] Portland Cement Association, PCA, Concrete Information، **Concrete Slabs Surface Defects: Causes, Prevention, and Repair**, 2001, IS-177-07.

[30] ACI 224.1R-93 (Re-approved 1998), American Concrete Institute, **Causes, Evaluation and Repair of Cracks in Concrete Structures,** Reported by ACI Committee 224, American Concrete Institute, MCP05, 2005.

[31] D.W.S Ho, **Durability of Concrete**, Edited by: W.f. Chen, J.y. Richard Liew, The Civil Engineering Handbook, 2nd ed. CRC Press LLC, 2003.

[32] ACI 302.1 R-04, American Concrete Institute, **Guide for Concrete Floor and Slab Construction**, Reported by ACI Committee 302, American Concrete Institute, MCP05, 2005.

[33] Portland Cement Association PCA web site, Concrete Technology, FAQS, **What causes efflorescence and how can it be avoided?,** http://www. cement.org, visited on 20/08/2008.

[34] Five Star Products INC., **A Professional's Handbook on Grouting and Concrete Repair**, 2007.

[35] Wikipedia, The Free Encyclopedia, **Geography of the Gaza Strip**, Web page http://en.wikipedia.org, last modified on 14/08/2007, visited on 15/7/2008.

Annex "A"

MANUAL

FOR

DAMAGE ASSESSMENT IN GAZA STRIP BUILDINGS

CONTENTS

CHAPTER 1: INTRODUCTION

Reinforced concrete structures are often exposed to many types of damages and deteriorations due to different causes and exposure conditions during their life cycle. These causes may be natural or manmade. Natural disasters, wars, conflicts, etc. normally result in sudden destruction, while long neglect, abuse, environmental factors, inadequate design, and construction, etc. result in progressive deterioration [1]. Both old and new concrete buildings need rehabilitation (repairing, restoration, protection, and/or strengthening) when suffering deteriorations, damages, defects, changes in use, and/or code upgrading. Repairs can range from the basic repair of a form-related defect, to the complex, rehabilitation of a load bearing structure [2].

Field studies indicated that a large percentage of house buildings in Palestine suffer of structural and/or deterioration problems. There is a need to rehabilitate almost 30% of existing housing stock, while 45% of the existing housing stock can be extended [3].

1.1 REHABILITATION OF STRUCTURES

Rehabilitation of existing structures is the process of repairing or modifying a structure to a desired useful condition [4]. It involves the improvement of existing structures physical condition through repair, restoration, protection, and/or strengthening after defects are encountered [5].

1.1.1 Causes for Rehabilitation

Sudden destruction or progressive deterioration of buildings would result in damages that need rehabilitation or replacement. Rehabilitation of structures is one of the fastest growing areas of engineering. The adverse influence of environmental factors after long neglect and the demand of increasing load levels have led to problems in load carrying capacity and long term durability of many structures. Furthermore, there are many structures that require either rehabilitation or demolition because of inadequate design/detailing, poor construction practice, natural or manmade destruction, etc. The replacement of every structure which showed signs of deterioration or that didn’t comply with requirements of present day loading levels, would be unthinkable both practically and economically [1].

1.1.2 Rehabilitation Needs

It is important that a thorough investigation of the nature and extent of the damage be carried out by appropriate professionals. The objective must be to treat the causes as well as the symptoms. Successful rehabilitation of damaged or deteriorated concrete structures requires professional assessment, design, management, and execution of a technically correct concept all in accordance with the highest quality standards.[6] Uniform design procedure for repair and strengthening of existing structures still, however does not exist. Some countries are in the process of developing relevant repair standards and specifications, for example European repair standards are now under development [7].

The decision on whether to rehabilitate or demolish a damaged structure is dependent on the anticipated functional life span requirements of the structure and the availability of cost-effective structurally upgrading solutions [1].

1.1.3 Advantages and Disadvantages of Rehabilitation

Rehabilitation of existing structures has many advantages over the construction of new buildings. Rehabilitation may be preferred for various reasons including [1]:

- a- It is normally cheaper than demolition and new construction.
- b- It requires fewer raw materials thus saving natural resources.
- c- Rehabilitation is normally quicker.
- d- Existing buildings may be in better locations.
- e- Worldwide experience has demonstrated that rehabilitation provides more returns on investment.

Rehabilitation of damaged structures may, however have some difficulties including [1]:

- a- The need to evaluate the material and structural characteristics of the existing damaged structure related to load carrying capacity and durability.
- b- Lack of standard design and analysis method which can be readily applied to rehabilitated structures.
- c- Architectural and use constraints related to existing spaces, location of structural elements, and configuration.
- d- Limitation of relevant practical experience.
- e- Difficulties in specifying and management or rehabilitation works.

1.2 GAZA STRIP PARTICULARITY

Gaza Strip is a coastal region located at the Mediterranean Sea. Normally, this location makes many reinforced concrete structures in the area susceptible to aggressive actions due to the high relative humidity and the high salts concentration in the atmosphere especially near the coast. These aggressive actions constitute a major factor in the corrosion of steel reinforcement which in turn causes many types of damages to existing concrete structures. In addition, concrete structures in Gaza Strip face several defecting criteria in their life starting from their design stage. These normally include faults in design, faults in the construction processes, defects in the materials, and chemical actions, etc.

On the other hand Gaza Strip is an occupied region that faces violent invasion due the Israeli attacks by several types of manmade destructions such as destructive missiles and bombs that destroy buildings and cause multiple types of damage to existing structures.

Until now, there is a no national standard or nationally adopted assessment method in Palestine to be followed in the assessment and evaluations of existing structures regarding their structural strength, safety, and serviceability.

This Manual describes a new developed approach for assessment of damages in reinforced concrete structures. It has been developed to assist engineers in planning their assessments in a uniform way taking into consideration the rehabilitation needs and the prevailing conditions in Gaza Strip.

CHAPTER 2: ASSESSMENT OF EXISTING STRUCTURES

The conditions of existing reinforced concrete (RC) constructions need to be evaluated periodically or in certain circumstances to insure the adequacy of structural elements to carry their imposed loading, and to verify soundness of the whole structure. The reasons for this arise from several factors such as:

1- The tendency of RC elements to deteriorate due to many factors and exposure conditions.
2- The need to upgrade or modify these structures.
3- Other accidental events and manmade destructions that may occur and cause distress or damage to buildings.

Before attempting any repair or rehabilitation of an existing building, it is necessary to have a planned approach of assessment to investigate its condition. While the diagnosis of damage or deterioration in some cases is reasonably straightforward, it may not be so in many cases that will require a thorough technical inspection and an understanding of the behavior of the structural component under consideration. This task should be assigned to qualified and expert engineers who can complete the assessment in a well managed process that results in accurate diagnosis and suitable remedy of the problem using the optimal approach for both assessment efforts and repair techniques [8].

2.1 DEFINITION OF ASSESSMENT OF EXISTING STRUCTURES

Assessment of existing structures is defined as: "A planned regime of inspection and testing of the structure by suitably experienced and qualified engineers to know the condition of the structure and to understand the cause or causes of deterioration so that the subsequent repair strategy is appropriate for both rectifying the existing defects and resisting future deterioration"[5].

A proper assessment will include surveying of the current condition of the structure, diagnosis of the causes of defects or deterioration, defining remedial actions to be carried out, and selecting the most appropriate intervention action according to the condition of the structure and the owner's requirements [9].

2.2 SCOPE OF THE ASSESSMENT

The main objective of assessment of existing structures is to ensure safety and serviceability of the structure at the owner's convenience. This can be achieved by a planned regime of inspection and testing of the structure in order to:

1- Assess the condition of the structure and identify the defects.
2- Understand the cause or causes of damage.
3- Decide the intervention action.
4- Recommend and specify the optimum solution of the problem.

Owners may be suspicious that their constructions might be under risk due to any unusual defect. The structure condition is supposed to be checked by the assessment team during site visits and visual inspection. In many cases the experts are able to directly evaluate the defects, relate symptoms to their causes, evaluate the effect of defects on the safety of the structure, and describe the remedial action to be followed.

2.3 THE ASSESSMENT APPROACH

The approach consists of three alternative routes depending on the scope of the assessment and the extent of damage. Its steps are designed to be planed, implemented, and evaluated at each assessment stage to minimize the assessment efforts and consequently the cost of assessment, in addition it helps in adequately assess the condition of the structure and recommend the appropriate intervention action.

2.3.1 Characteristics of the Approach

The proposed approach is suitable for use in Gaza Strip. Also it can be suitable for use in other countries or regions of similar circumstances (economy, types of constructions, environmental factors, etc.) and has the following characteristics:

1. The cost of the assessment is low since the assessment engineer is oriented towards a route proportional to the extent of damage from the first step without going into un-necessary details or investigations.

2. It guarantees the efficient assessment of damages and defects since all of its steps need planning and preparation before implementation. This enables the judgment of why, how, and when to do an activity in order to only perform the

necessary tasks that lead to reasonable prognosis of the cause of damage and its identification.

3. The approach suggests the selection of the intervention action based on comparative cost estimates for rehabilitation alternatives besides other technical aspects to repair the structure in an optimized way. This is to account for possible inadequate methods of assessment in local practice for repair that depend mainly on experience of assessment engineers.

4. The approach is not complicated and can be used for all assessment causes by any number of rehabilitation engineers with variable technical backgrounds but minimum experience is certainly required.

2.3.2 Applicability of the Approach

The approach applicability was verified through its application on various case studies with different causes, damage types, and extent. It showed that it is suitable for use in Gaza Strip. It can be used for the following purposes:

1. To determine the feasibility of changing the use of a structure, retrofitting the structure to accommodate a different use from the present one, enlarging the structure and/or changing its appearance.
2. To determine the structural adequacy and integrity of a structure or selected elements for current load or structural upgrading.
3. Prior to preparing a structural capacity certificate to an existing structure for the purpose of obtaining a municipality license.
4. To evaluate the structural problems or distress resulting from expulsions, overloads, fire, flood, foundation settlement, abrasion, fatigue, chemical attack, weathering, inadequate maintenance, inadequate design, poor construction practices and any unusual loading or exposure conditions.
5. To determine the feasibility of modifying the existing structure to conform to current codes, standards, and regulations.

2.3.3 Limitations of the Approach

The assessment approach is specially designed for reinforced concrete structures in small scale projects or individual buildings as the general case of Gaza Strip constructions. There are no limitations regarding the number of team members or their technical backgrounds. Certainly assessment teams have to possess a sufficient experience in the field of assessment, evaluation and rehabilitation of existing structures that should be attained by professional training besides academic knowledge obtained during their university study period.

Also all the requests for assessment in Gaza Strip can be assessed using the approach for all types, causes, and extent of damage.

2.3.4 General Description of the Approach

The proposed assessment approach consists of three routes with five main steps as shown in Fig. 2.1. Since the steps are designed to be sequential in time, each one depends to a large extent on the previous steps.

It is important to clearly define the objective of the assessment that meets the owner's needs and requirements before starting the assessment process. This can be done after a meeting with the owner to get relevant information about his complaints and objectives, and fully evaluate his needs.

The assessment process as a whole and the involved steps in particular depend largely on the scope of assessment, the owner's requirements, and the budget constraints. The starting point of the proposed assessment approach is the site visit from which three different routes can arise according to the extent of damage. Generally each route consists of a number of steps. The steps consist of activities which may have several tasks.

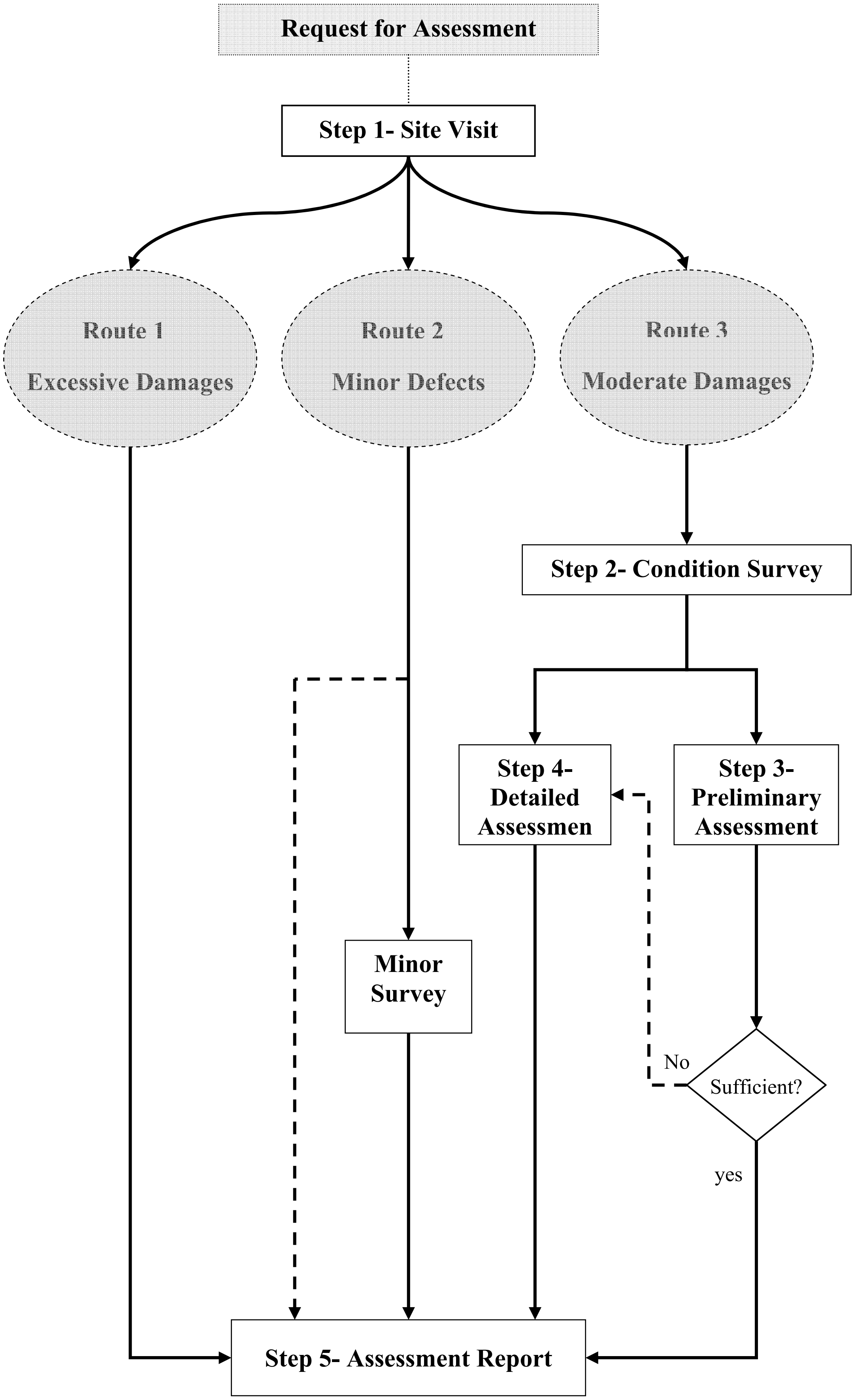


Fig. 2.1 Schematic Diagram of the Proposed Assessment Approach

2.3.4.1 Routes

Three routes are proposed. The selection of which route to follow depends on the type and extent of the detected damage determined by the assessment team after the site visit. Different rehabilitation teams could in some cases reach different conclusions related to the assessment of the condition of the structure and hence the selection of the appropriate route depending on their relative experiences, building importance, assessment consequence cost, and owner's expectations, etc. Nevertheless, the following criteria will help the assessment teams to decide on the route category:

*Route 1- Excessive Damages***:** In some cases where excessive and severe damages are found propagating in the building such that rehabilitation could not be feasible, no further investigations are needed. In this case demolition of the building or the elements under consideration is the only appropriate intervention action.

Route 2- Minor Defects: For the cases where minor defects such as defects in concrete finish, blistering, hair cracks, etc. are encountered, the defects could be described, located and quantified during the site visit or in a minor survey. Then a report is prepared containing complete description of the case, and suggestions of repair methods for the encountered defects.

Route 3- Moderate Damages: This is the main route of assessment. It could be followed in the cases where damages can not be readily assessed by experience, and need to be more precisely investigated before rehabilitation. In such cases, several steps are needed to map and appraise the damage, evaluate the current condition of the structure and prepare the recommended actions.

2.3.4.2 Steps

The main assessment steps are:

Step 1- Site Visit.
Step 2- Condition Survey.
Step 3- Preliminary Assessment.
Step 4- Detailed Assessment.
Step 5- Assessment Report.

2.3.4.3 Activities

Each step generally constitutes three related activities, planning, implementation, and evaluation as shown in Fig. 2.2. Before starting any assessment step, some preparation and planning is required in order to identify why, what, and how to do. Next the step is implemented as planned then findings are evaluated to determine the next step.

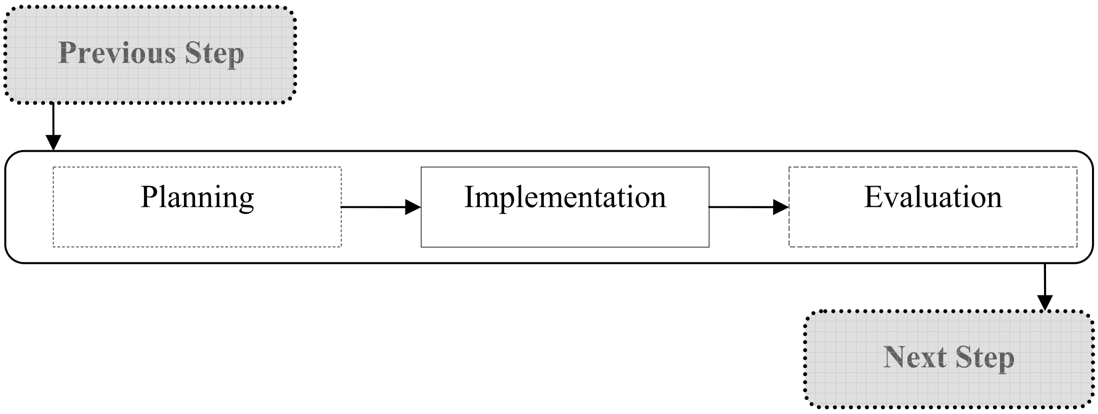


Fig. 2.2: Typical Activities of an Assessment Step.

2.3.4.4 Tasks

The activities of each step comprise a number of tasks. These tasks vary from an activity to another according to the case under consideration.

2.4 DETAILED DESCRIPTION OF THE APPROACH

The assessment main steps are discussed in reference to Fig. 2.1 as follows:

2.4.1 Step 1- Site Visit

A site visit is essential for any assessment. It is the key which opens or closes the process. It aims to let expert's eyes identify the case and take an initial impression regarding the condition of the structure. As shown in Figs. 2.2 and 2.3 it consists of three activities: Preparation, Implementation and Evaluation.

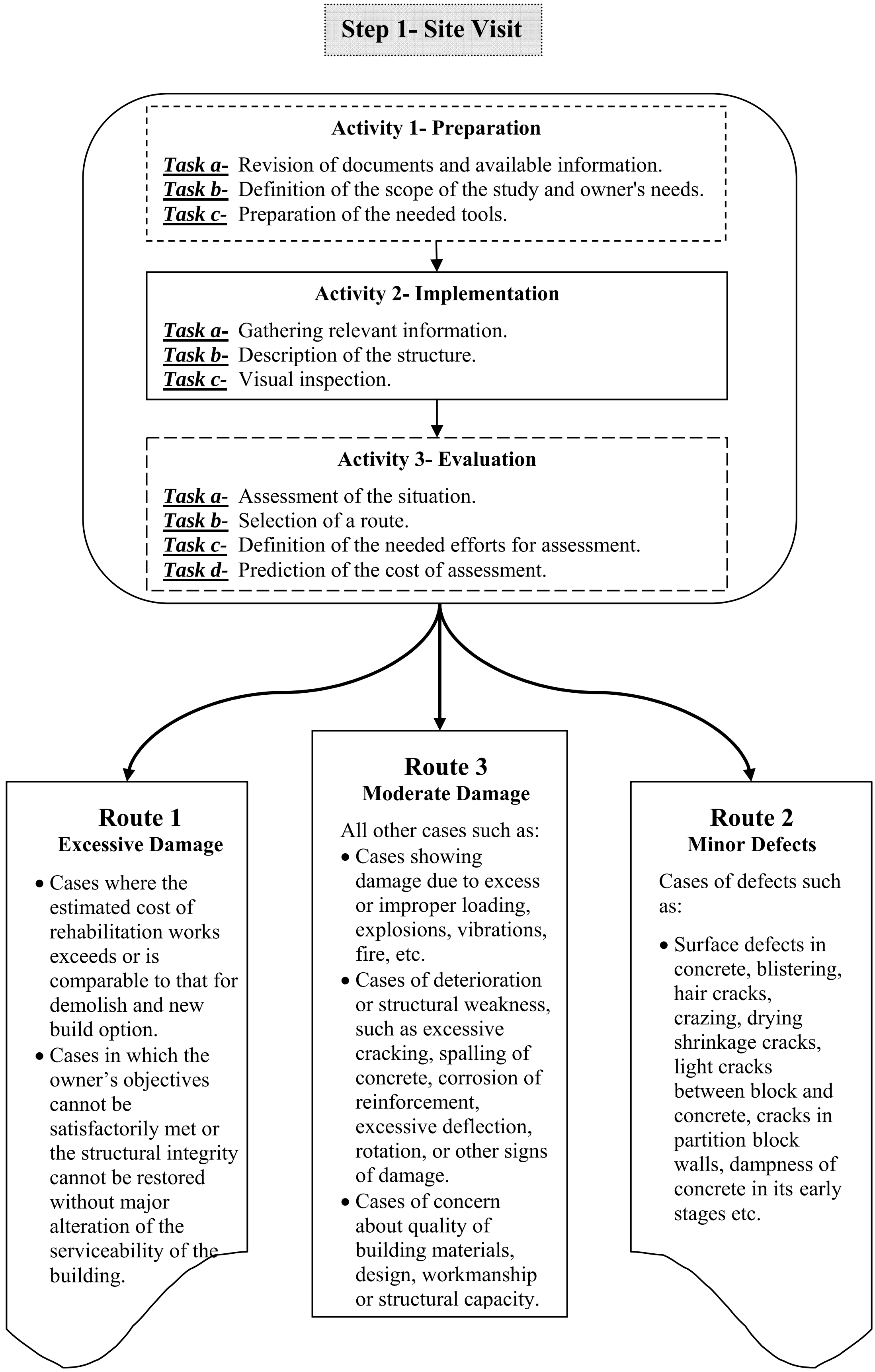


Fig. 2.3 Activities of the Site Visit and Probable Routes.

Activity 1- Preparation

The preparatory work for the site visit comprises the following tasks:

Task a- Revision of documents and available information taken from the owner, such as drawings of the building, previous test results, information about the problem, etc. This makes an initial background about the case.

Task b- Definition of the scope of the study according to the owner's needs by meeting the owner, listening to his complaint, and understanding his objectives.

Task c- Preparation of the needed tools to be used during the site visit such as a camera, a tape, a hammer, etc.

Activity 2- Implementation

During the site visit the following tasks are to be performed:

Task a- Gathering relevant information about the structure and collection of data concerning the problem, such as the type of building, its use, date of construction, first appearance of defects, etc. These information can be obtained from the owner or perhaps from other concerned people who may be met at site. Resident people may give valuable information about the problem and when they noticed it.

Task b- Description of the structure and the surrounding structures to be made during the site visit such as its location, dimensions, number of floors, environmental conditions, etc. The assessment team verifies the existing building with plans and drawings (if any); otherwise makes the necessary measurements and surveying works to maintain as built drawings.

Task c- Visual inspection of the structure, which is the most effective qualitative method for the evaluation of structural soundness and identifying the typical distress symptoms together with the associated problems. A walk through the structure with eyes on any unusual defect keeping in mind the background information about the problem, that determines to a large extent what to look for, will provide valuable information regarding workmanship, structural serviceability and material deteriorations. It is always necessary to carry a camera during such visit to take necessary photographs of the distressed structure and its members.

Visual inspection and collection of data would be helpful in planning the entire assessment. In some cases the site visit may be sufficient to conclude that the rehabilitation is not feasible such as in the cases of excessive damages. In other cases of minor defects such as hair cracks in plaster or block works, dampness in some locations and local defects in non-structural elements, the assessment team may find out that there is no need for the owner's suspicions since the defects are usual and could normally occur in any building.

Activity 3- Evaluation

After the site visit is completed the assessment team performs the following tasks:

Task a- Assessment of the situation, by deciding if damages or deteriorations are present and need to be assessed or not. If damages make the structure unsafe for the users, the assessment team has to determine any immediate safety measures to be considered such as supporting some elements, closure of some parts of the building, or even evacuation of the whole building until the completion of the assessment and repair.

Task b- Selection of a route to be followed in accordance with the damage extent. Three cases may be found: the damages are excessive, minor, or moderate. For each case a route of assessment can be followed: Route 1, Route 2, or Route 3 respectively.

Task c- Definition of the needed efforts for assessment according to the structure condition as judged during the site visit and the selected route. These efforts vary from a case to another, and comprise several actions such as testing, surveying works, excavation, etc. It is important in this case to have a good prediction of such efforts since they are directly related to the estimation of the cost of assessment. Experience of the team plays an important role in such issue.

Task d- Prediction of the cost of assessment as a preliminary estimate should be made roughly at this stage but to an acceptable degree of accuracy in order to negotiate with the owner and take his approval.

Thus, on completion of the site visit the assessment team has three routes to choose from as follows:

2.4.1.1 *Route 1: Excessive Damages*

In some cases, the site visit determines that it is not desirable to proceed with further assessment steps. This may happen in:

c- The cases of excessive damage and progressive deteriorations where repair materials are not available, or the estimated cost of rehabilitation works may approach that for demolish and new build option.

d- The cases in which the owner’s objectives cannot be satisfactorily met, or the structural integrity cannot be restored without major alteration of the serviceability of the building such as for example, column jacketing or section enlargement to the matter that may affect the accessibility or function of the structure.

In these cases the assessment team has to evaluate the findings of the site visit. Several factors can be considered in this evaluation such as cost of repair options compared with the cost of a new construction, availability of repair materials, availability of suitable repair technique, and availability of qualified contractors, etc. Among these factors usually the cost estimate of rehabilitation works compared with the cost of demolition and re-build option determines the case. This can be done mainly by experience of the assessment team.

This route is directly branched from Step 1 (Site Visit) to Step 5 (Assessment Report) without passing any other steps.

2.4.1.2 *Route 2: Minor Defects*

Sometimes only minor defects are encountered during the site visit. Minor defects are those defects not related to structural integrity or do not affect structural capacity such as defects in concrete finish, blistering after concrete placing, hair cracks, crazing, drying shrinkage cracks, light cracks between block and concrete, cracks in partition block walls, or dampness of concrete in its early stages. These defects once found, can be assessed directly by experience of the assessment team or have to be more investigated to find out their real causes, located, quantified, and described during the minor survey step that is described as follows:

Minor survey: is the step of identifying and describing minor defects encountered in a building by means of visual inspection and some measurements. These measurements include identification of boundaries of the defected areas, length of cracks, location of dampness, etc. Sometimes it is essential to exert some efforts to explore the source of defect as in the case of wetting or dampness, or to make some exploratory removal of some parts to uncover hidden objects, for example false ceilings that may hide some defects or blistering areas which may be caused by steel corrosion.

After the site visit, this route may go directly to the assessment report, or passes through the minor survey according to the case. The assessment report then should describe the findings and explain the methods of repair for the encountered defects.

2.4.1.3 Route 3: Moderate Damages

This route comprises the main branch of the assessment approach. It can be followed in the cases where the site visit reveals that various types of damages or defects are found, and the structural condition can't be readily assessed. It arises in many circumstances. The following are some examples:

i. Cases that show damage due to excess or improper loading, explosions, vibrations, fire, or other causes.
ii. Structures where there is evidence of deterioration or structural weakness, such as excessive cracking, spalling of concrete, corrosion of reinforcement, excessive deflection of some members, rotation, or other signs of damage.
iii. Cases that need assessment for change of use or upgrading especially when no adequate information regarding the used materials strength or structural details are available.
iv. Cases of concern about quality of building materials, design, or workmanship.

In such cases the assessment procedure comprises the following steps:

2.4.2 Step 2- Condition Survey

The Condition Survey is an examination of the structure for the purpose of locating and identifying areas of distress. It includes a mapping of the various types of defects that may be found, such as cracking, surface problems (disintegration, spalling, etc.), and deteriorations. The activities within the condition survey are illustrated in Fig.2.4:

Step 2- Condition Survey

Activity 1- Preparation	**Activity 2- Implementation**	**Activity 3- Evaluation**
Task a- Definition of the scope and methodology.	***Task a-*** Locating, measuring, and describing distress areas.	***Task a-*** Studying information.
Task b- Identification of practical restrictions and site preparation.	***Task b-*** Measuring dimensions and structural elements.	***Task b-*** Evaluation of damages.
Task c- Preparation of field documents for the condition survey.	***Task c-*** Acoustic impact testing.	***Task c-*** Determining missing information.

Fig. 2.4: Activities of the Condition Survey.

Activity 1- Preparation

Before starting the condition survey essential preparation and planning comprise the following tasks:

Task a- Definition of the scope and methodology of the condition survey keeping in mind the results of the site visit and the owner's needs.

Task b- Identification of the practical restrictions in conducting the condition survey and devising methods to overcome them- Such restrictions may be as closure of entrances of some places, no access to some locations such as floors or roof, and covering of some elements, etc. It is important also to define the safety measures for the condition survey team, and make necessary site preparations including access scaffolds, and working platforms, etc.

Task c- Preparation of field documents for the condition survey such as photocopies of available drawings (if any), work sheets and tables for recording field data, and a list of tasks with a work schedule.

Activity 2- Implementation

The following tasks are to be performed during the condition survey:

Task a- Locating, measuring, and describing distress areas including the description of damages, and measurement of cracks length, width, and depth. The assessment team has to concentrate on areas of critical sections in the building such as corners, wall openings, internal and external columns, mid-spans, and elements located close to the ground, etc. Also the team has to identify any noticeable damage. All the detected damages have to be clearly located on the available plans or at least on sketches of these plans. Furthermore, photographs of the damages and defected locations are valuable information for assessment in the later steps.

Task b- Measuring dimensions and various structural elements- This is to verify the measured dimensions with the available drawing details. If drawings are available, samples of spans length, and structural elements dimensions can be adequate to verify the as-built construction, otherwise adequate measurements and surveying works have to be made at least to reproduce plans to an adequate accuracy for the purpose of locating and describing damages.

Task c- Acoustic impact testing in several locations to identify if hidden damages are present or not- This is done by the assessment team using a hammer by applying slight knocks on the concrete surface at different locations and comparing the resulting sound from a location to another.

Activity 3- Evaluation

Evaluation at the end of the condition assessment comprises the following tasks:

Task a- Studying all the information gathered during the previous steps. This is done by categorizing the information into categories such as those related to the description of the case, the damages (types, sources, and causes), properties of construction materials, the strength of the structure, and its serviceability, etc.

Task b- Evaluation of damages- All the encountered damages have to be assessed regarding their real causes, extent, and effect on the structure. Based on the previous information and the assessment of damages the team can identify the needed assessment efforts.

<u>Task c-</u> Determining the missing information- According to needed assessment efforts determined in the previous task, the missing information that are needed to complete the assessment can be determined.

At this stage the team has to select the next step either the preliminary or the detailed assessment. This selection depends on several factors such as:

i. The scope of the assessment.
ii. The type and extent of damage.
iii. The amount of missing information needed.

If the assessment team is not certain which assessment to follow, it is recommended to start with the preliminary assessment, then evaluate if a detailed assessment is needed or not. Generally the cases that can be assessed in the preliminary assessment are those cases in which most of the needed information can be found at the condition survey level, and those having less severe damages.

2.4.3 Step 3- Preliminary Assessment

The objectives of the preliminary assessment are to assess the condition of the structure, set the rehabilitation alternatives, and decide if a detailed assessment is needed or not.

These objectives are achieved from the preliminary assessment as described in Fig. 2.5.

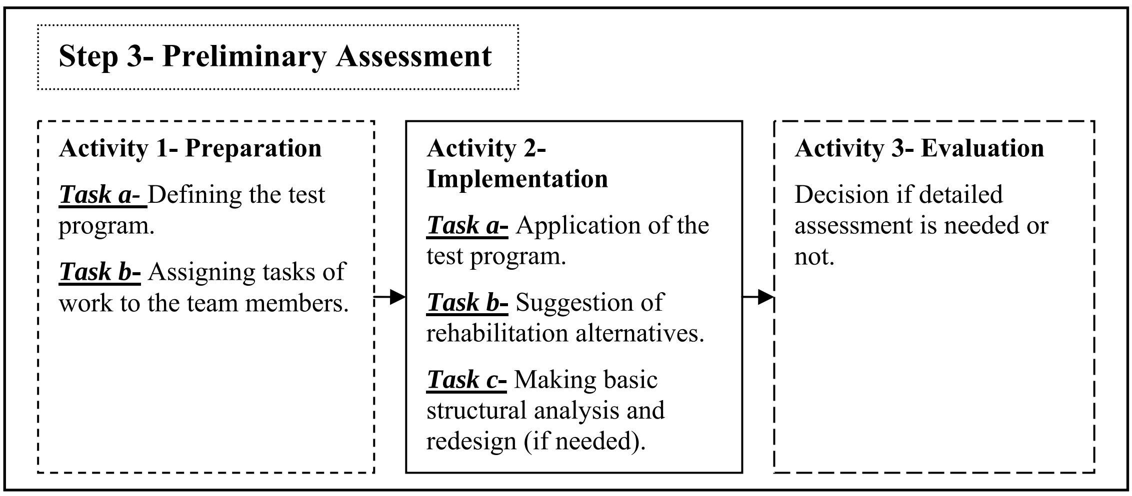


Fig. 2.5: Activities of the Preliminary Assessment.

Activity 1- Preparation

Preparation for the preliminary assessment includes the following tasks:

<u>Task a-</u> Defining the needed test program to compensate the missing information as determined in Step 2. In general a test program may includes exploratory removals to uncover some hidden objects, measurements of dimensions of some structural elements, non-destructive testing such as few rebound hammer tests, and cover meter tests in some locations to identify reinforcement. The purpose of such tests is to have information with acceptable level of accuracy about the structure to enable the structural capacity check, if needed. Sometimes no tests are needed in the preliminary assessment such as the cases in which adequate information about materials properties and sections detailing are available.

<u>Task b-</u> Assigning tasks of work to the team members- It is preferable at this time to start the assessment in parallel to save time. The task assignment may be in different forms according to the condition of the structure and the individual experiences of the team members. Such assignments include writing the report draft, making structural capacity checks, plotting plans, evaluation of test results, etc.

Activity 2- Implementation

Generally the main tasks to be involved during the preliminary assessment are:

<u>Task a-</u> Application of the test program- This can be done by local material testing laboratories as identified by the assessment team. Typical tests that can be made in this stage are: impact hammer test of concrete strength for various structural elements as needed, ultrasonic pulse velocity measurements, non-destructive detection of reinforcement steel using for example, micro cover meter, and taking possible samples for laboratory testing such as split concrete pieces or portions, reinforcing steel bars, or powder samples for chemical analysis. Results are reviewed by the team and conclusions about materials properties are made.

Task b- Suggestion of rehabilitation alternatives- The team who identified the problem causes and damage types and extents, sets few rehabilitation options appropriate to correct the situation. The alternatives are then evaluated by experience and preliminary cost analysis. The options are discussed with the owner to select a suitable rehabilitation option depending on the structural condition and availability of repair methods and techniques.

Task c- Making basic structural analysis and redesign- This is done in the cases that require structural capacity checks for some elements after assessment of sections, material properties, and rehabilitation option. The extent of such structural capacity check is limited to some calculations of loads, flexural capacity and shear strength of beams, or compressive strength of columns to assess the structural performance in current and/or future use, if any.

Activity 3- Evaluation

Decision if a detailed assessment is needed or not- The team has to decide this according to the results of the previous tasks. Some cases do not need detailed assessment such as the cases where at this level the structural condition is fully assessed and evaluated to be suitable for the intended use with the application of the suggested rehabilitation options. In cases where it is found that the structure as a whole or some of its parts are still in doubt regarding their structural capacity, further detailed assessment may be needed. Such cases can arise is some situations, for example, the cases where concrete compressive strength fails to meet the project requirements, and the preliminary structural capacity checks reveal that the structure or the elements under consideration fail to satisfy code requirements. In such cases a more detailed assessment step is to be followed to be certain that the situation is assessed to a higher degree of accuracy.

2.4.4 Step 4- Detailed Assessment

The detailed assessment is a process in which intensive efforts are made to get more precise information about the condition of the structure and the intervention action. Cases that require a detailed assessment are typically the cases that lack sufficient information to assess the building condition with confidence such as the cases of structural upgrading without the presence of sufficient structural details and material properties. This process is illustrated in Fig. 2.6.

Step 4- Detailed Assessment

Activity 1- Preparation:	→	**Activity 2-Implementation:**	→	**Activity 3- Evaluation:**
Task a- Defining the test program.		***Task a***- Documentation.		***Task a-*** Evaluation of materials and test results.
Task b- Getting owner's approval.		***Task b-*** Application of the test program.		***Task b-*** Structural evaluation.
Task c- Assigning tasks of work to the team members.		***Task c-*** Suggestion of rehabilitation alternatives.		***Task c-*** Evaluation of rehabilitation alternatives.

Fig. 2.6: Activities of the Detailed Assessment.

The detailed assessment comprises the following activities:

Activity 1- Preparation

The preparation for the detailed assessment considers three tasks as follows:

Task a- Defining the test program- The test program is one of the main features of the detailed assessment. Where testing is required, it is necessary to make an assessment of what specific information is needed, the purpose of each test and the information that it can provide. These have to be considered so that the appropriate tests are carried out. A testing program is usually required to give more precise information about several aspects regarding the condition of the structure. Generally the following are examples of such aspects:

i- Properties of the used building materials by testing representative and relatively large number of test samples.

ii- Excavation to foundation in order to determine foundation embedded depth, type, dimensions, concrete strength, and reinforcement.

iii-Surveying works to reproduce building drawings in the cases of no or insufficient structural details are available.

iv- Extent of deterioration in cases of reinforcement corrosion, for example testing to determine depth of carbonation, chlorides or sulfates, residual cross-section of reinforcement, etc.

v- Full load test for some parts of the structure where the material and sections information do not enable satisfactory structural capacity check.

vi- Soil bearing capacity in some cases.

Task b- Getting the owner's approval- Since the test program may be destructive for some parts, its cost may be relatively high, or special permits have to be obtained, the owner has to be informed about such issues in order to approve the assessment and its budget. A written agreement is preferable before starting the assessment.

Task c- Assigning tasks of work to the team members- As in the preliminary assessment, it is preferable at this time to start the assessment in parallel to save time. The task assignment may be in different forms according to the condition of the structure and the individual experiences of the team members. Such assignments include: writing the report draft, making structural analysis of the building, documentation, performing cost analysis of rehabilitation alternatives, evaluation of test results, etc. A time schedule of work can be prepared within this task.

Activity 2- Implementation

The implementation of the detailed assessment comprises the following tasks:

Task a- Documentation- Intensive effort should be exerted to locate, obtain, and review the pertinent documents relating to the structure. This is important to minimize the assumptions necessary to evaluate the structure. Typical information needed are related to design, materials, construction, service history, and repair history if any. Documents about such topics may be found at several institutions in Gaza Strip such as Municipalities, Ministry of Public Works and Housing, Association of Engineers, the project designer or sometimes the contractor. Contacting such institutions by visits, meetings, or communication tools may provide the team with valuable information that necessarily reduce the assessment efforts.

When the required documents are not available testing are usually required to compensate the missing information.

Task b- Application of the test program- Several activities and tests are to be performed by local material laboratories under supervision of the assessment team. More extensive sampling and testing is needed either to the whole structure or to selected parts for which the detailed assessment is made.

Task c- Suggestion of rehabilitation alternatives- All possible rehabilitation options that are appropriate to correct the problem have to be considered. Technical and financial analysis can be made for each alternative to serve as a basis for evaluation later on.

Activity 3- Evaluation

In general three tasks of evaluation are to be performed within the detailed assessment as follows:

Task a- Evaluation of materials and test results- Field and laboratory test results should be studied and evaluated to determine strength and quality of existing construction materials. For example when testing is performed for compressive strength of concrete, several types of tests may be performed such as impact hammer, ultrasound, and core tests. The results of these tests have to be correlated and evaluated by the assessment team to have the most reliable estimate of the in-situ concrete strength. Also tests for carbonation, chlorides, sulfates, etc, can be correlated to predict the variation of depth of influence of such chemical actions within the structure. Such evaluation enables the determination of locations that require repair, strengthening, or replacement.

Task b- Structural evaluation- Using the information obtained from the previous steps regarding dimension, geometry, and materials, the load-carrying capacity of the structure or portion under consideration can be determined. The choice of the evaluation method depends on factors such as the nature of the structure and the amount of information known. A common choice is evaluation by analysis, which is recommended when sufficient information are available. Also evaluation by analysis and load testing can be used in some situations where analytical methods give negative results or when the sections and the material characteristics of the structural elements cannot be determined.

<u>Task c-</u> Evaluation of rehabilitation alternatives- The suggested rehabilitation options have to be evaluated to select the optimum one. This can be done based on technical and cost considerations. Technical considerations are related to the repair materials availability, durability, and compatibility for original materials. Also they are related to the rehabilitation technique simplicity, practicality, and efficiency. On the other hand cost considerations include the direct cost of rehabilitation works, in addition to the indirect costs such as cost of closure of the building during rehabilitation.

Ranking for such factors is carried out by the assessment team according to the importance of the building, safety considerations, and owner's requirements in order to have an optimal option satisfying these considerations.

2.4.5 Step 5- Final Report

The final step of the assessment process is the assessment report. It has to reflect the efforts exerted by the assessment team, describe the condition of the structure in a professional and technical way and present documented information regarding the case. The entire investigation should be summarized in a comprehensive report describing the assessment method as a whole with sufficient description of all the findings including:

a. Purpose and scope of investigation.
b. Existing construction and documentation.
c. Field observations and condition survey.
d. Sampling and material testing.
e. Evaluation.
f. Findings and recommendations.

The recommended rehabilitation actions have to be fully described in the report with adequate details concerning the repair technique, needed materials, locations, construction details and drawings, etc.

Sometimes some protective measures to prevent or eliminate the occurrence of further damages or deteriorations should be addressed in the assessment report. This is to help building owners or users maintain the buildings in a proper way thus increasing their life span.

Also safety measures to be followed during preparation and implementation of rehabilitation works have to be pointed out.

2.5 CONCLUDED REMARKS

1. local conditions in Gaza Strip relating to rehabilitation of existing structures have been accounted for in the developed assessment approach as follows:

    a. Most of the projects in Gaza strip are of a small scale; hence, the damaged locations are of little value and do not need expensive or extensive assessment procedures. For example, when steel corrosion is encountered it could be either limited in few locations that could be repaired easily, or propagated in many locations that could be demolished and replaced. There is no need to use advanced techniques that give information regarding corrosion rate, propagation, effect on structural capacity, and when to start repair as usually needed in large scale projects. The approach suggests a route suitable for each case of damage to reduce the assessment efforts and hence the cost of assessment. Excessive damages follow Route No. 1 where no further assessment is needed. Minor defects are assessed in Route No. 2 and only a minor survey is sufficient to identify the damage perfectly. Furthermore, moderate damages that need more assessment efforts are assessed by following Route No. 3 in which the suggested assessment techniques are proportional to the value of the projects in Gaza Strip.

    b. Most of the encountered damages in Gaza Strip are of minor or moderate nature such as dampness, hair cracks, and cracks in non-structural elements, etc. These damages require few efforts of assessment that are addressed in the developed assessment approach. Furthermore, when localized deteriorations are found rehabilitation techniques are adopted for remedy of the problem without the need of complicated testing and evaluation procedures.

    c. Good quality building materials are generally in use in Gaza Strip. Only 6% of the damages were related to low strength concrete. This situation enabled the use of limited non-destructive testing that are sufficient to assess the structural capacity of the elements under consideration. The preliminary assessment step of the developed approach accounted for this situation and permitted the structural capacity checks based on such tests and available confidential information gathered during the assessment process.

d. The cost of the assessment is low since the approach orients the assessment engineers to a route proportional to the extent of damage from the first step without going into un-necessary details or investigations. This suits the economical situation in Gaza Strip.

e. In many assessments in Gaza Strip the experience of the assessment teams controlled the selection of rehabilitation options. To account for this inadequate method, the approach suggests the selection of the intervention action based on comparative cost estimates for rehabilitation alternatives besides other technical aspects to repair the structure in an optimized way.

f. Several institutions with various expertise undertake assessments of existing structures in Gaza Strip. For this reason the developed assessment approach is not complicated and can be used for all assessment causes by any number of engineers with variable technical backgrounds but minimum experience that is certainly required.

2. The practicality of developed assessment approach has been proven by verification of the approach with real case studies. It was demonstrated that the proposed assessment approach is applicable to a wide range of cases of damage in existing buildings in Gaza Strip. It was verified with a variety of case studies having different causes, types, and extent of damage.

   The site visit was found essential to define the route of assessment. Such routes when followed provide planned regime of inspection and assessment that enables the identification of the problem, discover its causes, and select the appropriate intervention action. The approach provides a clear guide to assessment practice. The selection of routes is based on the damages detected during the site visit. Cases with excessive damages could be directed to Route No.1 of the developed assessment approach without the need for additional steps. Minor defects when encountered need Route No. 2. Moderate damages could be adequately assessed in Route No. 3.

In some cases, the developed assessment approach if followed would result in the same results as previously assessed cases. But in the other cases local assessment practice have shown unsatisfactory results. The approach would give more rational and economical results.

3. The suitability of the developed assessment approach is not limited to Gaza Strip conditions only, but is suitable for other locations having the same circumstances as well.

CHAPTER 3: DEFECTS IN CONCRETE STRUCTURES AND REPAIR TECHNIQUES

3.1 INTRODUCTION

Concrete structures exhibit a variety of defects during their life time from the design stage to service stage. These defects vary from very simple and negligible defects which occur almost in all structures, to very severe and destructive deteriorations that may cause excessive damages to the structure or even its collapse. The assessment and repair of defects in existing structures require good knowledge and experience to identify the defects, their causes and how to prevent and repair them.

The working life of the structure may be reduced or extensive maintenance may be required as a result of deterioration of materials, usually steel subject to corrosion attack or concrete subject to aggressive chemicals. Evidence of this type of damage may appear after 15 or 20 years and is strongly environment dependent [10].

Case studies regarding defects occurring in existing buildings in Gaza Strip have shown that Gaza Strip environmental conditions play an important role in propagation of some types of defects such as deterioration of concrete and corrosion of steel reinforcement. Also some defects were associated with design errors, construction errors, and poor quality concrete. Fire as an accidental event caused many defects in a considerable number of cases as well, in addition to many damages that were caused by Israeli military attacks. These findings made it essential to review such defects in literature and make efforts in gathering information regarding the most common defect types occurring in concrete structures illustrated with photographs where possible. This is to give the assessment engineer a tool appropriate to easily identify the defects, detect their causes, and report the condition of the structure in a scientific and a standard way.

3.2 CAUSES OF DAMAGES IN EXISTING STRUCTURES

Damages in existing structures continue to be of a growing concern. Accurate information on the condition of concrete in existing structures is critical to evaluate its safety and serviceability. This information is required by decision makers to determine if repair or replacement is necessary and to select optimum repair techniques where conditions require [11]. A basic understanding of the causes of concrete deficiencies is essential to perform meaningful evaluations and successful repairs. If the cause of a deficiency is understood, it is much more likely that an appropriate repair system will be selected, consequently, the repair will be successful and its maximum life will be obtained. Symptoms or observations of a deficiency must be differentiated from their actual causes. Only after the causes are known, rational decisions can be made concerning the selection of a proper repair system [12].

In most cases, the defects in existing structures can be traced to one or more of the following types:

1. Signs of poor quality in design and construction: such as wetting or dampness, leakage, structural or non-structural cracks, foundation settlements, etc.
2. Physical damage such as freeze-thaw action, cracking due to thermal movement, and shrinkage cracking.
3. Mechanical damage due to for example, impact, explosions, abrasion, etc.
4. Chemical damage such as carbonation, chloride contamination or ingress, and Alkali-silica reaction.

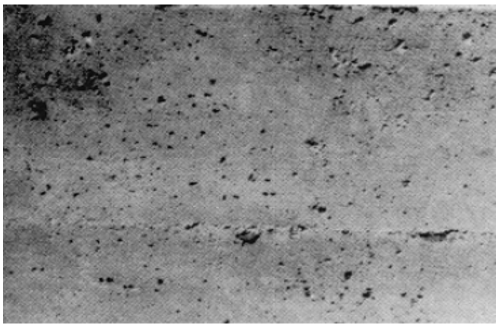
Progressive cases of damages and defects can arise and accelerate in certain environments and if the concrete has insufficient cover, or is porous [9].

Several ways can be followed to classify damages of defects. They can be classified according to their causes, types, or severity. The following section gives a classification of defects and damages in accordance with their causes.

3.2.1 Damages Caused By Construction and Design Errors

3.2.1.1 Damages Due To Construction Errors

When the concrete structure is newly constructed some types of damage attributable to unsatisfactory construction practice may occur. The damage may have an immediate effect on the structural integrity. Poor construction usually leads to reduced durability which manifests itself in later years. Also poor construction practices and neglect can cause defects that lead to the cracking and concrete deterioration [10]. Typical construction faults that may be found during a visual inspection include bug holes, evidence of cold joints, exposed reinforcing steel, honeycombing, irregular surfaces caused by improperly aligned forms, and a wide variety of surface defects and irregularities. These faults are typically the result of poor workmanship or the failure to follow accepted good practice [13]. Various types of construction faults are shown in Fig. 3.1.



Bugholes (www.usace.army.mil)

Honeycombing (Al-Nasser Hospital-Gaza)

Cold Joints (www.enhance-solutions.com)

Blistering (www.structuraldesigns.com.au)

Segregation (Al-Nasser Hospital-Gaza)

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

Fig. 3.1: Typical Construction Faults in Concrete.

3.2.1.2 Damages Due To Design Errors

The design errors can be broadly categorized into two types: inadequate structural design and poor design details as follows:

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 areas of high stress concentration. These problems can be prevented with a careful review of the design calculations and detailing [10].

b- Poor Design Details

Detailing is an important component of a structural design. Poor detailing may contribute to the deterioration of the concrete since missing details may lead to improper construction practice or materials deficiency in quality the matter that results in deteriorations and defects in concrete structures [10].

3.2.2 Damages in Concrete Due to Physical Causes

3.2.2.1 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 [14].

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

Fig. 3.2: Plastic Shrinkage Cracks.
(www.cement.org/tech/faq_cracking.asp)

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 form 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 [15].

b- Settlement Cracking

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 slump, and decreasing cover. The degree of settlement cracking may be intensified by insufficient vibration or by the use of leaking or highly flexible forms [15].

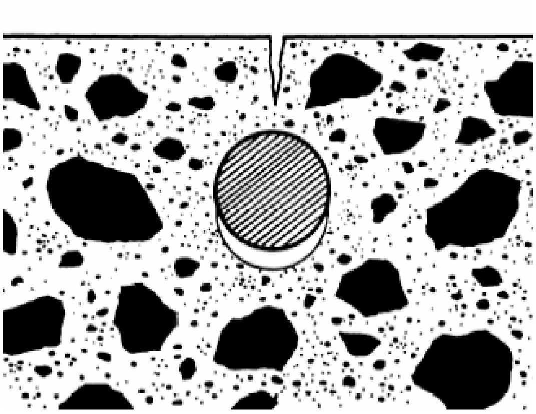


Fig. 3.3: Settlement Cracks.
(ACI 224.1- R93)

3.2.2.2 Damages in Concrete after Hardening

a- Drying Shrinkage Cracks

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.

Fig. 3.4: Craze Cracks.
(www.prairie.com)

When the tensile strength of concrete is exceeded, 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.

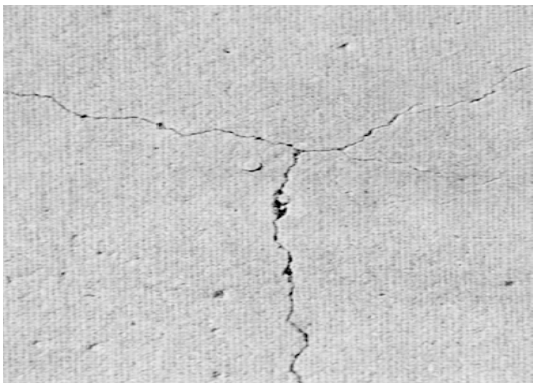


Fig. 3.5: Drying Shrinkage Cracks due to Improper Joint Spacing.
(ACI 302.1- R04, www.portcement.org)

Drying shrinkage can be reduced by increasing the amount of aggregate and reducing the water content [15].

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 that shown in Fig. 3.5

b- Damages Due to Thermal Stresses and Fire

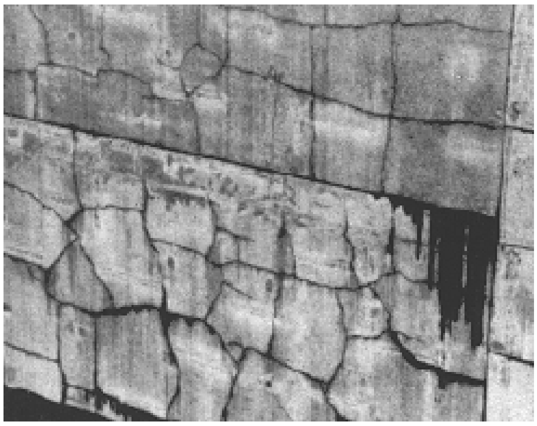


Fig. 3.6: Pattern Cracking Caused by Restrained Volume Change.
(www.usace.army.mil)

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 columns, piers, beams, and footings, 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 [15].

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 fire accelerates. The extent of damage depends on the temperature reached, loading conditions under fire, and characteristics of the concrete, which includes the quality of concrete and type of aggregates used [16]. Typical fire damage is shown in Fig.3.7.

Fig. 3.7: Typical Fire Damages.
(IUG Library Building-March, 2008)

c- Weathering Cracks

The weathering processes that can cause cracking include:

1. Freezing and thawing.
2. Wetting and drying.
3. Heating and cooling.

Damage 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 in 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 [15].

3.2.3 Deterioration of Concrete Due to 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 [8]. The main causes of deterioration of concrete structures are briefly explained as follows [16]:

3.2.3.1 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. The time before repair, often referred to as the service life of the reinforced concrete element, is determined by the total time of these two stages [16].

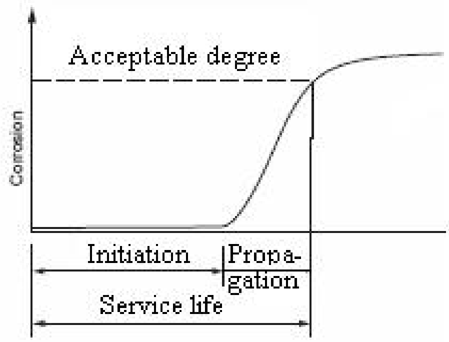
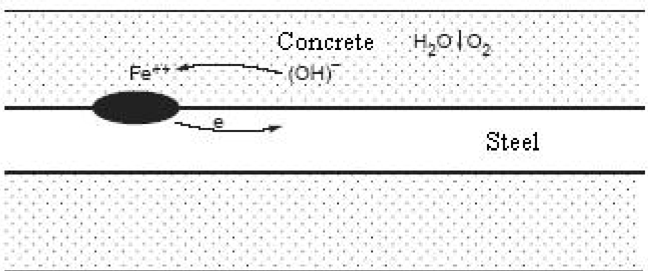


Fig. 3.8: Schematic Diagram of Corrosion Process of Steel in Concrete [16].

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.



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

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

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

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 [8].

3.2.3.2 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].

3.2.3.3 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].

3.2.3.4 *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].

3.2.3.5 *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].

3.2.3.6 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 COMMON DEFECTS IN CONCRETE

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.

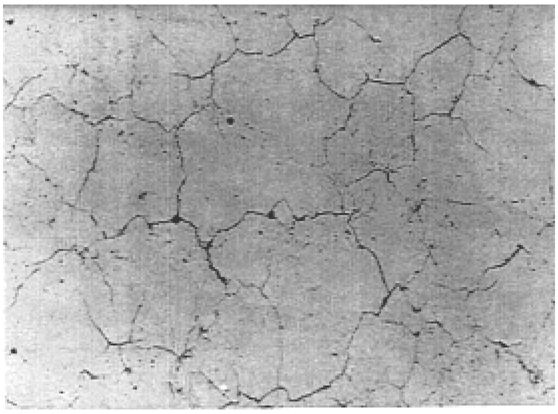


Fig. 3.10: Craze Cracks (Map Cracking).
(ACI 201.1R-92)

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 [17].

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 [17].

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. Dusting is the result of a thin, weak layer, called laitance, composed of water, cement, and fine particles usually

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

appears as a result of construction faults or concrete weakness. Floating and trowelling concrete with bleed water on it mixes the excess water back into the surface, further weakening the concrete 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 [17].

3.3.4 Efflorescence

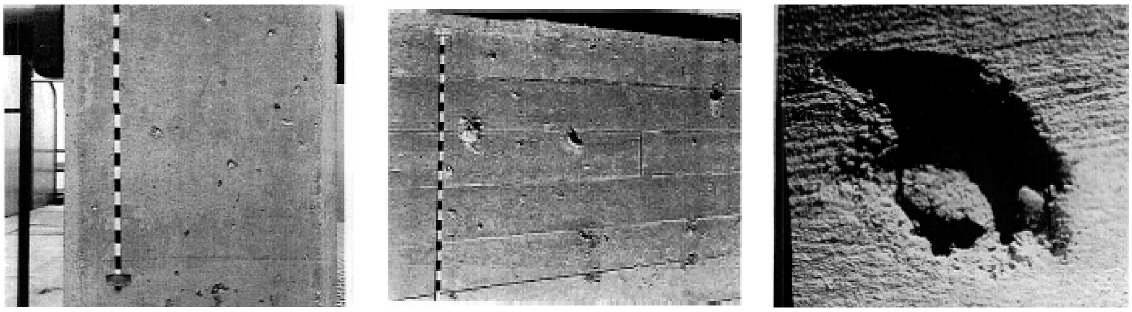
Efflorescence can be considered a type of discoloration. It is a deposit, usually white in color that occasionally develops on the surface of concrete, often just after a structure is completed. Efflorescence is usually harmless. In rare cases, excessive efflorescence deposits can occur within the surface 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 [18].

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

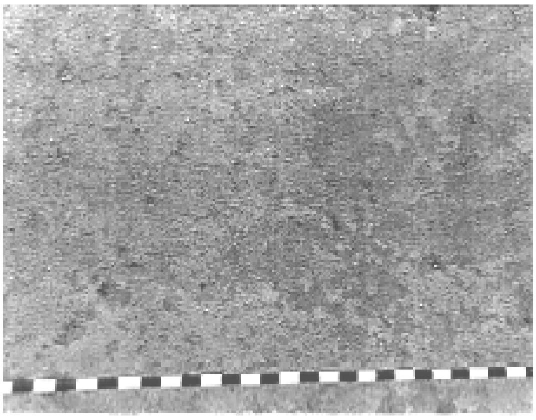
Fig. 3.12: Popouts. (ACI 201.1R-92)

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.

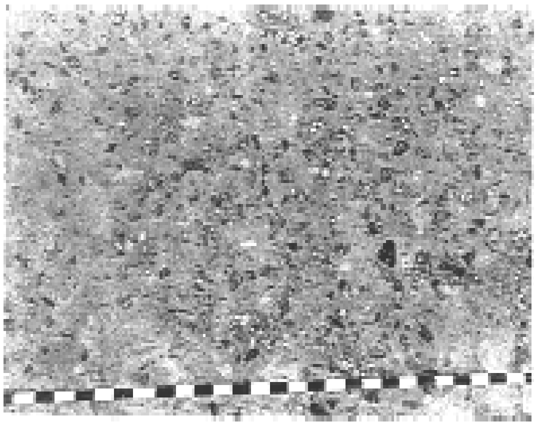
Popouts are considered a cosmetic detraction and generally do not affect the service life of the concrete [14].

3.3.6 Scaling

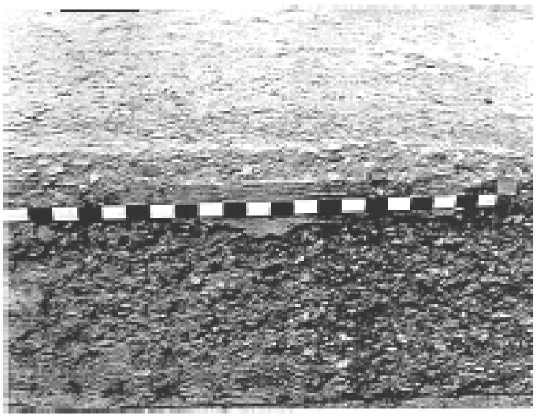
Scaling is a local flaking or peeling away of the near-surface portion of hardened concrete or mortar. It may be light scaling (loss of surface mortar without exposure of coarse aggregate), medium scaling (loss of surface mortar 5 to 10 mm in depth and exposure of coarse aggregate), severe scaling (loss 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 [19].



Light Scaling



Medium Scaling



Severe Scaling

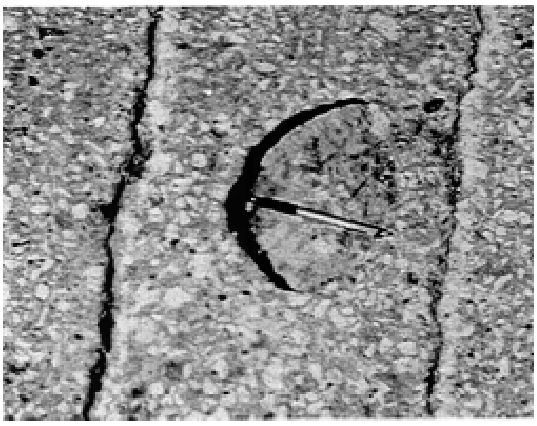
Very Severe Scaling

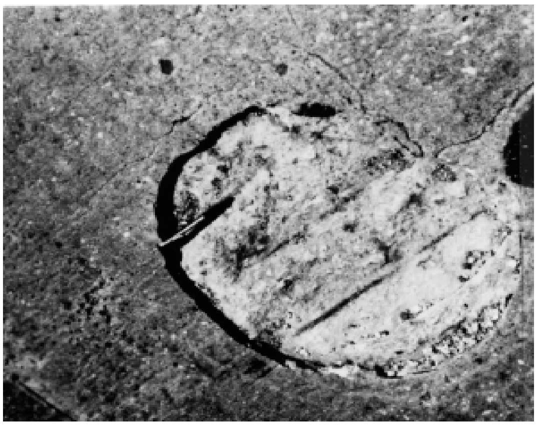
Fig. 3.13: Types of Scaling. (ACI 201.1R-92)

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 [18,19].

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].





(a) Small Spall **(b) Large Spall**

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

Common defects in existing concrete structures are summarized in table 3.1. They are briefly described with their probable causes, how they can be avoided or prevented, and how they can be repaired. This information is intended to be as a guide to assessment engineers who are responsible for the condition survey of existing structures and not to replace their judgment.

Table 3.1: Common Defects in Concrete structures [reproduced from Cement Concrete & Aggregates Australia, "CONCRETE BASICS a Guide to Concrete Practice", Sixth Edition August 2004, and "Avoiding Surface imperfections in Concrete Datasheet", July 2008**]**

Type of Defect	Image	Cause	Prevention	Repair
COLOR VARIATION Difference in color across the surface of concrete. May appear as patches of light and dark.		1- Uneven or variable curing conditions. 2- Applying a different brand or type of cement to the surface as a 'drier'	1- Use an even concrete mix when placing, compacting and finishing and keep concrete evenly moist. 2- Do not use driers	Not necessary, if the surface will not be covered, repeated gentle treatments with a weak acid may solve the problem, or apply a surface coating.
CRAZING A network of fine cracks across the surface of concrete.		• Minor surface shrinkage in rapid drying conditions. (Low humidity and hot temperatures, or alternate wetting and drying.)	• Finish and cure concrete correctly.	Usually not necessary, If the crazing looks too bad then a surface coating of a paint or other overlay sealer can be applied to cover and/or minimize the effect of the cracks.
DUSTING A fine powder on the concrete surface which comes off on your fingers.		1- Finishing before the bleed water has dried. Or finishing during the rain. 2- Not cured properly, or the surface is drying too quickly. 3- Concrete subject to severe abrasion or of a low grade	1- Let any bleed water dry up before trowelling. 2- Cure correctly, Protect concrete from drying out too quickly in hot or windy conditions. 3- For harsh conditions use a stronger concrete	Where dusting is minimal the application of a surface hardener can be beneficial. If the surface is showing significant wear distress it is essential to remove all loose material by grinding or scrapping the surface to a sound base and then applying a suitable topping.

Table 3.1 contd.

Type of Defect	Image	Cause	Prevention	Repair
SPALLING When the slab edges and joints chip or break leaving an elongated cavity.		1- Edges of joints break because of heavy loads or impact with hard objects. As concrete expands and contracts the weak edges may crack and break. 2- Entry of hard objects, such as stones, into joints may cause spalling when the concrete expands. 3- Poor compaction of concrete at joints.	1- Design the joints carefully. Keep joints free from rubbish. 2- Keep heavy loads away from the joints and edges until they have properly hardened. 3- Ensure proper compaction.	For small spalled areas: scrape, chip or grind away the weak areas until reaching sound concrete, making sure you brush the old concrete clean of any loose material. Then refill the area with new concrete or repair mortar. Compact, finish and cure the new patch carefully. Care should be taken that all joints be maintained and not filled. For large spalled areas: use proper technique.
EFFLORESCENCE A white crystalline deposit sometimes found on the surface of concrete soon after it is finished.		1- Sometimes mineral salts are dissolved in water. If water with dissolved mineral salts collect on the concrete surface as water evaporates salt deposits are left on the surface. 2- Excess bleeding can also result in efflorescence.	1- Use clean, salt-free water and washed sands. 2- Avoid excessive bleeding.	Remove efflorescence by dry brushing and washing with clean water. Do not use a wire brush. Wash with a dilute solution of hydrochloric acid.

Table 3.1 contd.

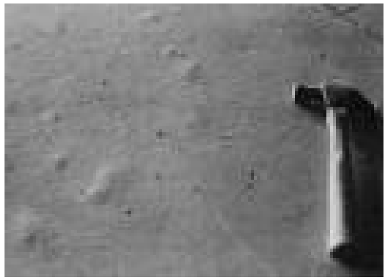
Type of Defect	Image	Cause	Prevention	Repair
HONEYCOMBING Too much coarse aggregate appears on the surface.		1- Poor compaction, segregation during placing or paste leakage from forms. 2- A poor concrete mix with not enough fine aggregate causing a rocky mix.	1- Take care during placing concrete to avoid segregation. Compact concrete properly. Good watertight formwork. 2- Use a better mix design.	If honeycombing happens only on the surface it can be rendered. Rendering means to cover the surface with a layer of mortar. If honeycombing happens throughout the concrete it may need to be removed and replaced.
BLISTERING Blisters are hollow, low profile bumps on the concrete surface filled with either air or bleed water.		• They are caused when the fresh concrete surface is sealed by trowelling while trapping air or bleed water under the surface. This may particularly occur in thick slabs or on hot, windy days when the surface is prone to drying out.	• After placing, screeding and floating leave the concrete as long as possible before trowelling, which seals the surface. Cure to prevent evaporation. If blisters are forming delay trowelling as long as possible and take steps to reduce evaporation.	Grind off the weakened layer to an even finish.

Table 3.1 contd.

Type of Defect	Image	Cause	Prevention	Repair
BLOWHOLES (BUGHOLES) Individual rounded or irregular cavities formed against the formwork. Small blowholes (less than, say, 10 mm) tend to be approximately hemispherical while larger ones are irregular and often expose coarse aggregate particles.		Permeable forms and poor compaction. Blowholes tend to be more prevalent towards the top of a concrete placement than at the bottom, due to the increased compaction and static head at the bottom layer of the pour.	The use of permeable forms may significantly reduce, if not eliminate, the incidence of blowholes.	Generally, they are regarded as an appearance problem though a concentration of large blowholes may lead to loss of durability.
FLAKING Discrete pieces of the surface become detached leaving a rough indentation behind. The pieces are usually flat.		Flaking is caused by inappropriate finishing techniques that seal the surface and trap the water which would otherwise have risen to the surface as bleed water. This water accumulates below the surface forming a plane of weakness and resulting in delamination of the surface layer.	• Avoid the use of finishing techniques that tend to seal the surface. • In summer, use an evaporative retarder to prevent rapid surface drying and give time for the bleed water to rise to the surface.	• Grind the delaminated areas back to sound concrete and apply a proprietary sealing compound. • Remove the delaminated concrete and apply a bonded topping or epoxy coating to the floor.

Table 3.1 contd.

Type of Defect	Image	Cause	Prevention	Repair
POPOUTS Popouts are roughly conical depressions in the concrete surface created by localized pressure within the concrete, usually occurring after the concrete has been in place for some time. They can be categorized as small, medium or large depending on whether the diameter of the cavity is 10 mm or less, 10 to 50 mm, or greater than 50 mm respectively.		They are usually caused by the expansion of a deleterious aggregate particle located near the surface or the expansion (due to freezing) of water absorbed by an aggregate particle. In either case, the particle breaks away from the mass of the concrete carrying with it the surface layer of mortar. Experience has shown that generally it is coarser sizes of deleterious aggregate, e.g. 9.5 to 19 mm, that give rise to the problem. Deleterious aggregates include shale, but contaminants such as pieces of wood, clay and coal can also cause popouts.	• Use aggregates free from deleterious particles that are known to cause popouts. • Use higher strength concrete that will better resist the tensile stresses leading to popouts. • Ensure that good concrete practices are employed on the project as poor compaction and inadequate curing will increase the likelihood of popouts.	• Filling the popout crater with a mortar of similar color to the base concrete.

3.4 REHABILITATION TECHNIQUES

3.4.1 Introduction

Rehabilitation of existing structures is the process of repairing or modifying a structure to a desired useful condition [4]. It involves improvement of existing structures physical condition through treatment (repair, restoration, protection, and /or strengthening) after defects are encountered to restore or enhance one property or more such as durability, structural strength, function, or appearance, and thus bringing degradation under control to enable the structure to continue serving its intended purpose. This can be either repairing to bring concrete back to a state similar to the original, or using methods to arrest deterioration processes to enable ongoing service [5].

Once the assessment of a damaged structure has been completed and the decision of repair has been taken, the most appropriate repair technique or combination of techniques has to be selected through available options that can be used. Several rehabilitation principles and methods for repair are available in literature concerning repair of structural defects and protection of the structure from further deterioration. Principles for repair are used as basic objectives to be fulfilled by repair methods [20]. Several principles for repair were adopted by different institutions world wide, for example, by the European standards. The main principles for a remedy of a problem are:

1. Protection against ingress of adverse agents.
2. Moisture control.
3. Concrete restoration.
4. Structural strengthening.

For each principle several repair methods can be used. The selection of a repair method depends on several factors such as:

1. Type and extent of distress.
2. Location of distress.
3. Environmental exposure.
4. Appearance.
5. Cost.

6. Availability of repair materials.
7. Availability of skilled personnel and equipments [8].

The last two factors are of high importance at local level because of the political situation in Gaza Strip and the lack of practical experience.

3.4.2 Materials for Repair

A wide range of repair materials for concrete is available in the world at different costs and performance characteristics. Their application range covers:

1. Materials for surface preparation.
2. Chemicals for rust removal from corroded reinforcement.
3. Passivators for reinforcement protection.
4. Bonding agents.
5. Structural repair materials.
6. Non-structural repair materials.
7. Injection grouts.
8. Joint sealants.
9. Surface coatings for protection of reinforced concrete.

These products are generally pre-proportioned and in pre-weighed packs together with accompanying instructions regarding mixing procedure, dosage and application procedure etc. [8]

Repair materials may be classified into three general groups: Cement based, Polymer based, and Polymer modified materials [21].

Cement based materials are those generally prepackaged materials requiring only the addition of water. Their physical properties are very similar to those of concrete and they achieve strengths to or greater than the concrete being repaired. Also thermal coefficients of expansion are nearly identical to that of concrete. The main disadvantage of most cementitious products is that they don't develop adequate bond strength.

Polymer-based materials include epoxies, polyesters, and acrylics. They are most commonly used where chemical resistance is required. Most of the polymer-based repair materials achieve high strength and good bond to a properly prepared and dry substrate.

There are some disadvantages to these materials:

1. They are generally more difficult to work with as compared to cement based materials.
2. They exhibit varying degrees of toxicity and flammability. So they should be used with caution.
3. Proportioning the components and mixing are critical to proper curing.

Polymer-modified materials are also polymer based with modifications or improvements including increased bond strength, reduced permeability, increased resistance to freezing and thawing, and increased flexural strength. The specific property improvement to the modified mortar and concrete varied with the type of latex used.

Applications of these materials include floor leveling, concrete patching, and bridge deck overlays.

In addition, all of the polymer-based repair materials are more expensive than cement based materials. Regardless of the type of repair material, an adequate inventory should be kept in stock. Any repair material chosen to be kept in stock must have an adequate shelf life. These materials may remain in inventory for months and must retain their efficacy. A shelf life of a minimum of 6 months is highly recommended [21].

3.4.3 Factors Affecting the Selecting of Repair Materials

When selecting a repair material, several properties could be considered. Some important properties in considering a concrete repair material are:

1- Length change.
2- Bond strength.
3- Compressive strength.
4- Consistency.
5- Working time.
6- Thermal coefficient of expansion.
7- Durability [21].

3.4.4 Repair Techniques

Several repair methods and techniques are available nowadays. They cover all aspects of damages occurring in existing concrete structures. Although several classifications of these techniques can be found in literature, the following classification was selected for repair methods according to their physical function or method of action [20]. This selection is made to match with the previously described principles of repair.

3.4.4.1 Surface treatments

Surface treatments are used to maintain old structures and protect them against different deterioration processes or reduce the deterioration rate. They can increase the length of the initiation period preceding the degradation by limiting transport of water, chloride, sulfate, acids or some other aggressive compounds. On concrete structures where degradation has started the deterioration rate might be reduced, and then consequently the service life can be extended by the use of surface treatments.

Surface protective treatments can be classified into three types:

1- Hydrophobic impregnation.
2- Impregnation.
3- Coating.

Hydrophobic impregnation produces a water-repellent surface; impregnation produces a discontinuous thin film (usually 10µm – 100µm) that partly fills the capillaries, and coatings produce a continuous layer (typical thickness 0.1mm – 5.0mm) on the surface of the concrete [20].

3.4.4.2 Injection of Cracks

Cracks are normal in reinforced concrete structures. However, they can have a negative influence on the durability and integrity of the structure and in many cases action has to be taken. Before taking any action however, it is important to determine whether injection/sealing is an appropriate remedial measure. The cause of the cracking must be identified, as treatment methods will vary depending on whether the cracks are dormant or live. The moisture conditions within the concrete must be known. In some cases, injection or sealing of cracks is not appropriate. Injection should not be used where the reinforcement is corroding or where the cracks are caused by corrosion.

Crack injection, although often used in conjunction with strengthening, is not a strengthening method in itself. It is used to repair cracks in reinforced concrete components to avoid progressive damage, maintain integrity of the concrete and improve durability. While crack injection improves the tensile capacity of the concrete locally, the overall stiffness of an injected beam is only marginally modified, as new cracks can develop in the un-repaired concrete.

There are two main methods to treat cracks [20]:

a. Injection: an internal treatment used to fill most of the cracks and voids and thus seal the cracks.

b. Surface sealing: an external used to protect the concrete or the reinforcement from ingress of aggressive materials. Sealing can be divided into two groups:

    i. Membranes applied either as liquids or preformed (bonded or un-bonded) sheets.
    ii. A suitable sized groove is made and filled with an appropriate sealant.

Injection is usually made with hydraulic binders, polymer binders or gels injected through holes drilled into the cracks. It can be carried out through a half pipe attached to the concrete surface along cracks.

Surface sealing with grooves is usually used for live cracks. The width of the groove is dimensioned in such a way that the total movement will not exceed about 25% of the width.

The depth of the groove is dependant on the sealant, which can be some type of mastics, or thermoplastics. Membranes can be used to seal just the cracks or the whole surface. At live cracks an area along the crack is usually un-bonded [20].

3.4.4.3 Patching

Patching is a repair technique for concrete structures which consists of replacing the lost, unsound or contaminated concrete with a material that can be new concrete, a repair mortar, a grout, etc. The objective of patching is to restore the esthetical and geometric properties of the structure in order to maintain its structural safety and increase its durability.

If the reinforcement is corroded, or corrosion is likely to occur as a result of a thin, non-existing or contaminated cover, the procedure of patching also includes cleaning the reinforcement rust and protecting it from further corrosion before the concrete cover is restored.

Patching consists of the following stages [20]:

a. Identification of unsound/contaminated concrete
b. Removal of unsound concrete
c. Cleaning of concrete substrate and reinforcements
d. Application of the repair material
e. Surface treatment of the concrete substrate in order to increase bond strength

Patching is a very cost effective repair method, fast and very effective if it is well executed. On the other side, if execution is not right, patch repairs will be of no use for the structure. It is essential for the sake of the repair that the surface of the concrete substrate is completely cleaned, it is treated to improve bond strength, and the repair material is compatible with the old concrete.

Patching is an effective method for repair of local areas where there is no necessity to increase the strength of the structure. Patching is usually carried out to repair damage which does not compromise the structural strength. If the deterioration has affected strength, there are other methods which may be more suitable for the repair. Patching is also used to repair damages that may affect the appearance of the structure [20].

3.4.4.4 Repair of Deteriorated Concrete and Reinforcement Corrosion

The occurrence of corroding reinforcing steel can usually be detected by the presence of rust stains on the exterior surfaces, visible cracks along steel bars, spalling of concrete cover to reinforcement, and by the hollow or drummy sounds that result from tapping the affected concrete with a hammer. It can also be detected by measuring the half cell potentials of the affected concrete using special electronic devices manufactured specifically for this purpose. When the presence of corroding steel has been confirmed, it is important to define what actually caused the corrosion because the cause of corrosion will usually determine which repair procedure should be used. Once the cause of damage has been defined and mitigated proper preparation of the corroded steel exposed during removal of the deteriorated concrete becomes important. Steel that has been reduced to less than half its original cross section by the corrosion process should be removed and replaced. The remaining steel must then be cleaned to remove all loose rust, scale, and corrosion byproducts that would interfere with the bond to the repair material. Corroded reinforcing steel may extend from areas of obviously deteriorated concrete well into areas of apparently sound concrete. Care must be taken to remove sufficient concrete to include all the corroded steel [22].

Various repair techniques are applied to reinforced concrete structures that are deteriorated due to chemical and physical attacks, bad workmanship or due to other factors. The following repair techniques have been implemented for reinforced concrete works in Gaza [7]:

1- ***Carbonation in reinforced concrete- Reinforcing steel within the carbonated zone and honeycombed concrete***. The scope of work covered is the replacement of carbonated and honeycombed concrete surrounding the steel reinforcement bars by low permeability repair mortars followed by the application of a penetrating, reactive primer and top coat system.

2- ***Honeycombed concrete- Carbonation or chloride induced corrosion where large volumes are involved or where trowel applied mortars are considered less suitable***. The scope of work covered is the concrete replacement using high-strength, free-flowing cementitious micro-concrete followed by application of a penetrating, reactive primer and top coat system.

3- ***Chloride induced corrosion in reinforced concrete, chloride penetration from external environments only-*** The scope of work covered is the replacement of chloride contaminated concrete by low permeability repair mortars followed by the application of a penetrating, reactive primer and top coat.

4- ***Chloride induced corrosion in reinforced concrete contamination by chlorides inherent within the concrete.*** The scope of work covered is the removal of chloride contaminated concrete from the vicinity of the reinforcing steel and replacement with low permeability repair mortars followed by the application of a penetrating, reactive primer and top coat system.

3.4.4.5 Strengthening with reinforced concrete

a- Introduction

Strengthening with reinforced concrete can be used on structures affected by corrosion, salt-frost attack, mechanical wear, acid attack, alkali silica reaction (surface attack), sea water attack, leaching by pure or natural water, accidental load, overload, and structural load.

Strengthening with reinforced concrete can be divided into two different types:

a. Bonding of hardened concrete to hardened concrete, typically associated with the use of precast units in repair and strengthening.
b. Casting of fresh concrete to hardened concrete using an adhesive bonded joint forming a part of the structure requiring composite action.

The structural repair with reinforced concrete consists normally of the following actions [19]:

i. Removing contaminated, cracked, or defective concrete.
ii. Removing and replacing corroded reinforcement.
iii. Adding protection to the reinforcement.
iv. Casting and/or adding new reinforced concrete section for strengthening of the structure.

b- General Considerations

It is important to ensure compatibility with the parent concrete, as well as full composite action. Pre-preparation is crucial, to ensure bond with the substrate and the reinforcing bars. Good workmanship is paramount for all application methods, which may be used [20].

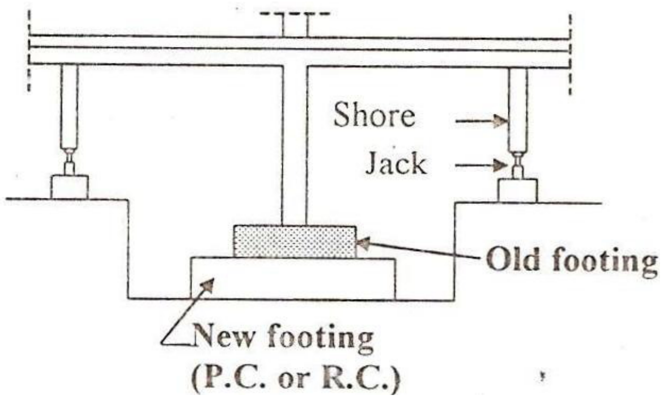
c- Strengthening Techniques for RC Elements [3]

There are many common methods for strengthening of various reinforced concrete elements in use worldwide. Their design is dependant on the type of the structural deficiency and the needed sectional capacity after strengthening. Also the design considerations are different from those for new constructions.

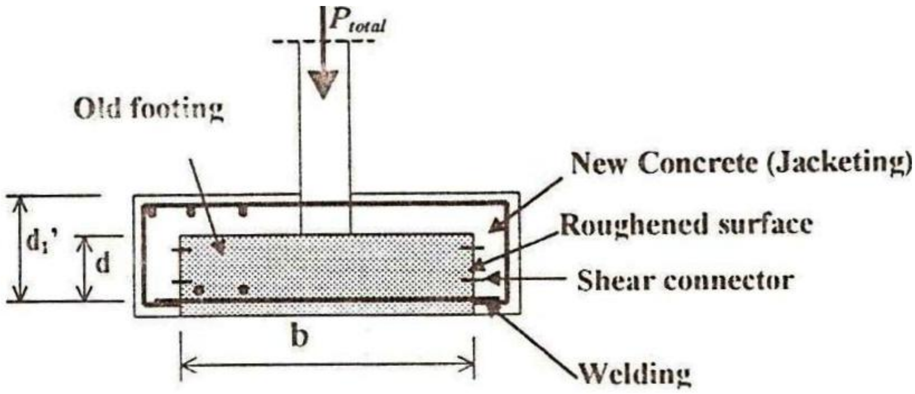
1- Strengthening of Shallow Foundations

Several methods for strengthening of shallow foundations could be used including:

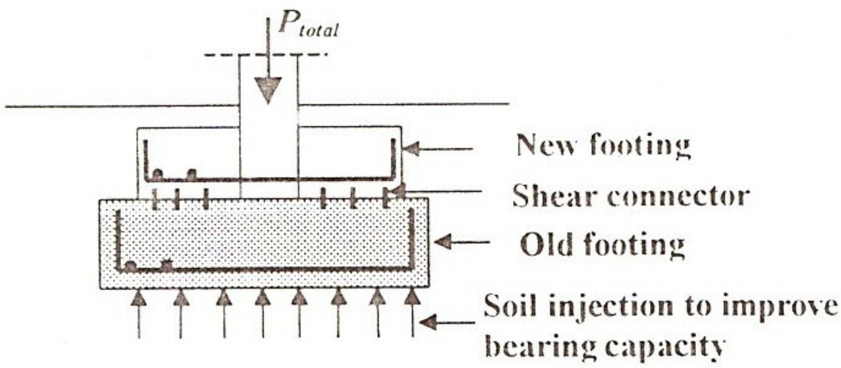
i. Increasing of bearing areas under spread footings thus increasing the resistance against wide-beam, two-way shear and bending moments as shown in Fig. 3.15.



(a) New footing underneath



(b) Jacketing on top



(c) New footing on top

Fig. 3.15: Increasing Bearing Areas under Spread Footings [3].

ii. Connecting spread footings to work as a combined footing or a mat foundation as illustrated in Fig. 3.16.

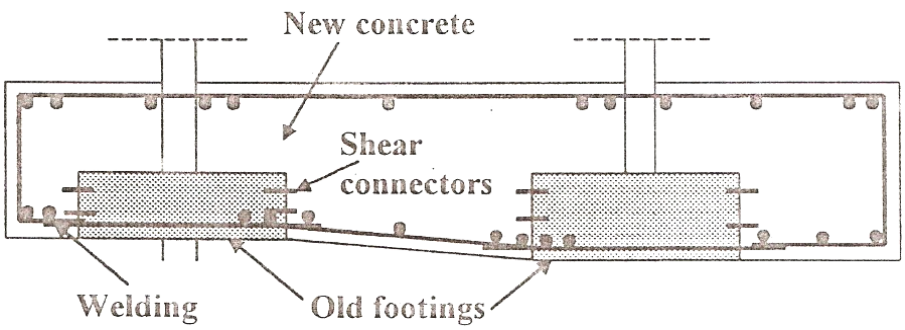


Fig. 3.16: Connecting Spread Footings [3].

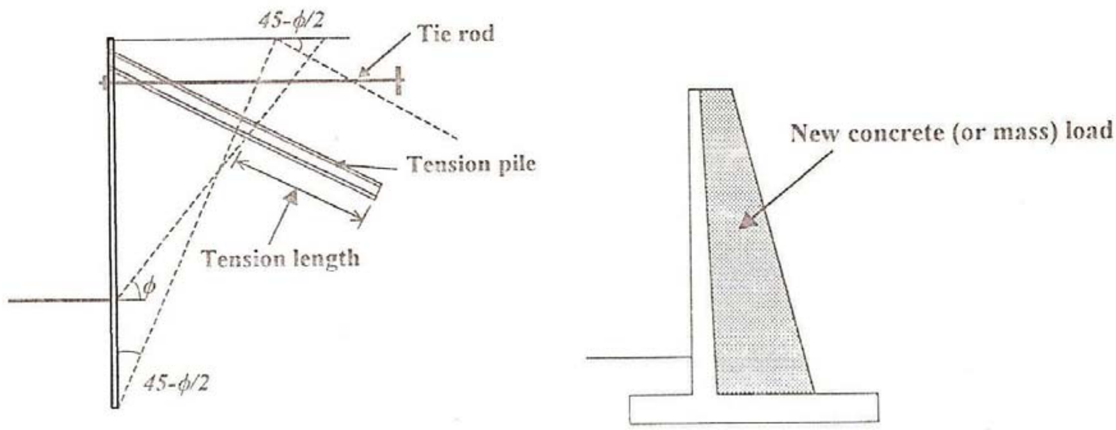
iii. Increasing the depth of a mat foundation by a reinforced concrete overlay thus modifying the flexure and shear resistance of the foundation.

2- Strengthening of Retaining Walls

The strengthening or retaining walls comprises the following:

i. Increasing the retaining wall cross-section.

ii. Increasing resistance to overturning forces by adding tie rods or tension piles as shown in Fig. 3.17 (a), or converting the wall to a gravity retaining wall as shown in Fig. 3.17 (b).



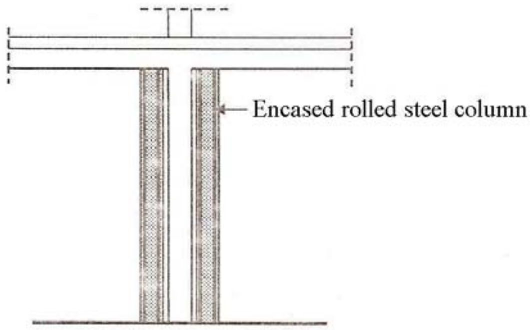
(a) Adding a tie rod or a tension pile **(b) Conversion to a gravity retaining wall**

Fig. 3.17: Increasing Resistance of Retaining Walls to Overturning [3].

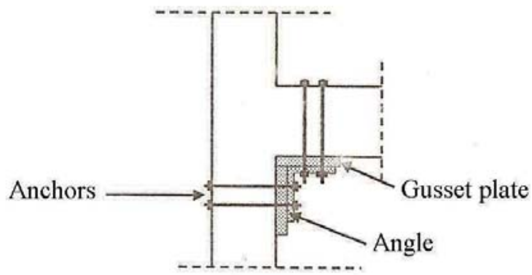
3- Strengthening of Walls and Columns

Several methods for strengthening walls and columns can be used such as [3]:

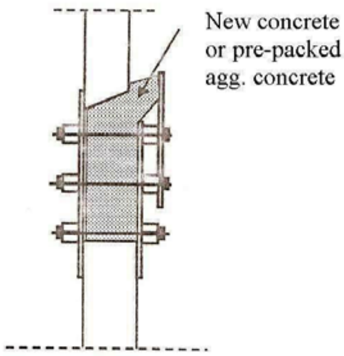
i. Permanent propping using encased rolled steel columns to increase the load carrying capacity as shown in Fig. 3.18 (a).
ii. Increasing flexural capacity by use of moment resisting connections as in Fig. 3.18 (b).
iii. Replacement of a damaged or defected part of columns or walls as shown in Fig. 3.18 (c).
iv. Strengthening by the use of jacketing techniques as illustrated in Fig. 3.18 (d).



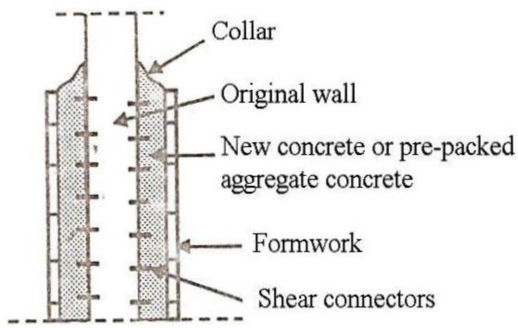
(a) Permanent propping



(b) Moment resisting connection



(c) Replacement of part of column or wall



(d) Jacketing of walls

Fig. 3.18: Strengthening of Walls and Columns [3].

Fig. 3.19 illustrates reinforcement details for column jacketing according to the number of faces of encasement.

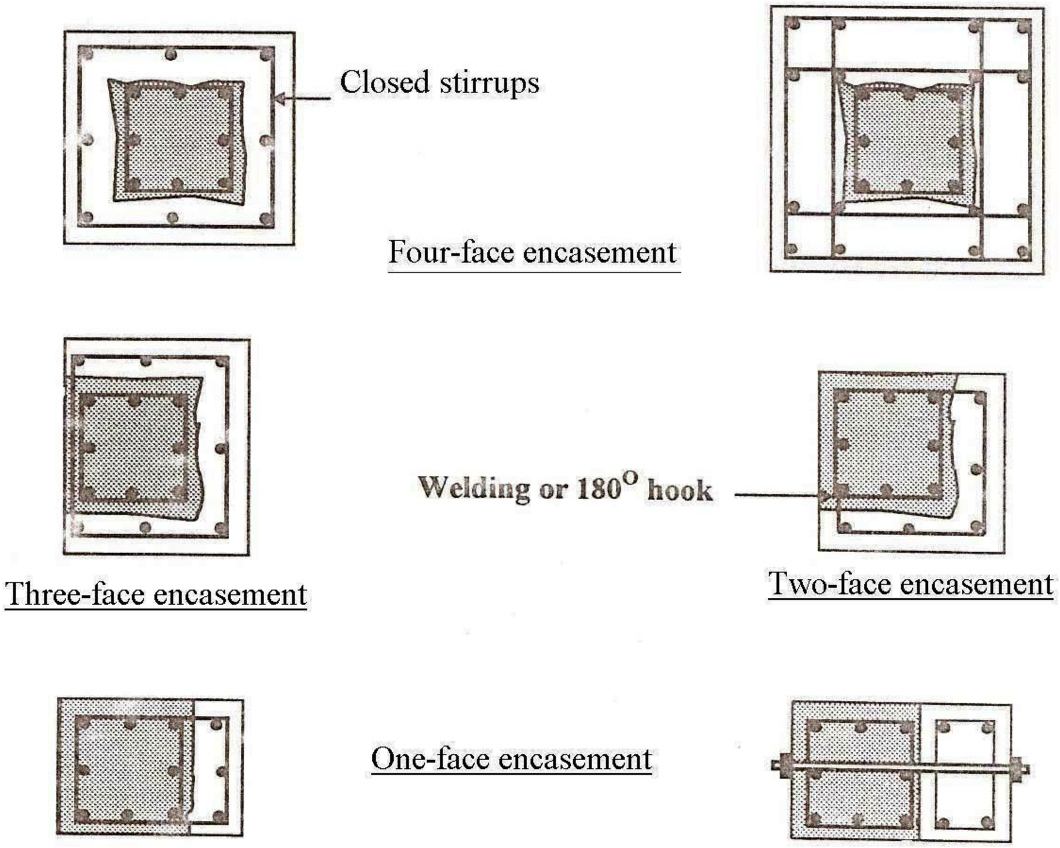


Fig. 3.19: Jacketing Reinforcement Details [3].

4- Strengthening of Beams

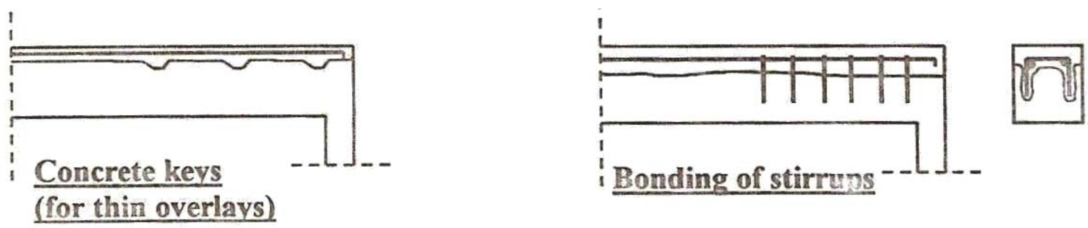
Beams can be strengthened using the following methods:

i. Adding a compression concrete overlay and resisting of laminar shear as shown in Fig. 3.20 (a).

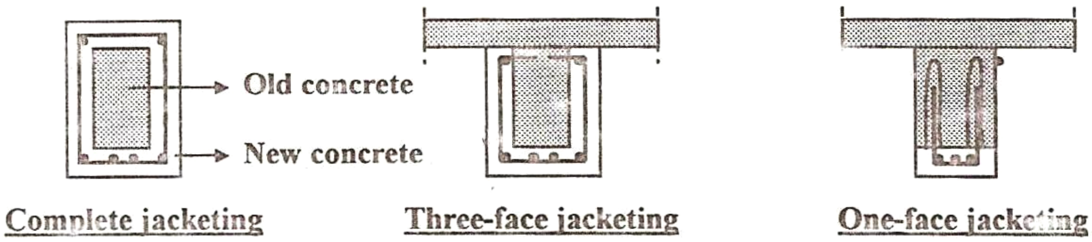
ii. Increasing the depth and/or the width of beams by jacketing as illustrated in Fig. 3.20 (b).

iii. Increasing transverse reinforcement to modify shear and torsion resistance of beams as in Fig. 3.20 (c).

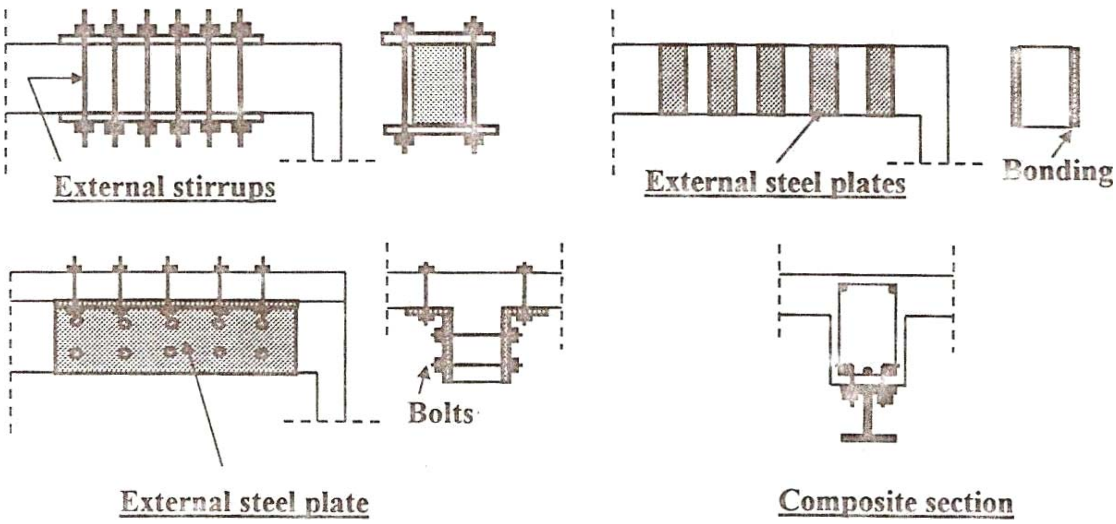
iv. Increasing shear and flexural capacity of beams by span shortening using additional new concrete or steel columns as illustrated in Fig. 3.20 (d).



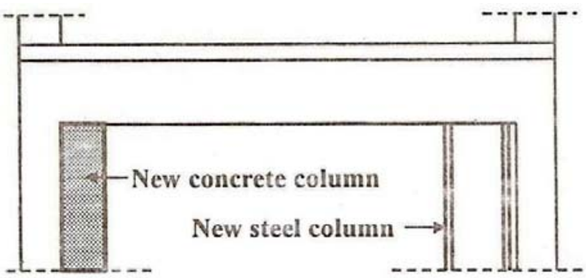
(a) Adding a compression concrete overlay and resisting of laminar shear



(b) Increasing depth and/or width (Jacketing of beams)



(c) Increasing transverse reinforcement



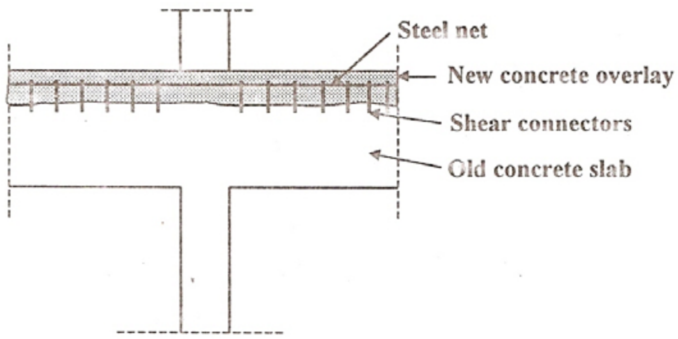
(d) Span shortening

Fig. 3.20: Strengthening of Beams [3].

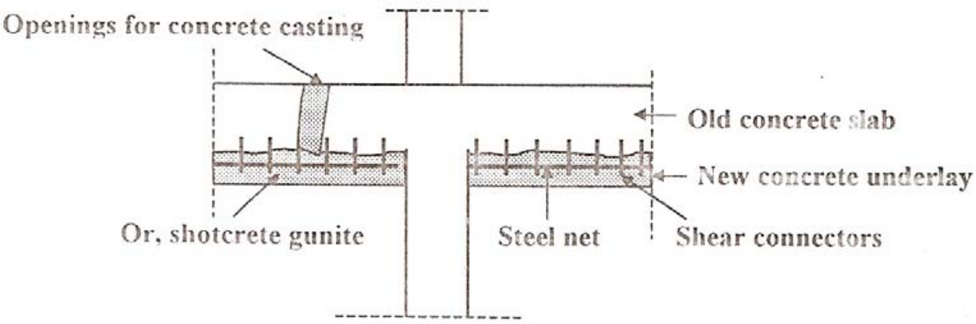
5- Strengthening of Slabs

Slabs can be strengthened by the following techniques:

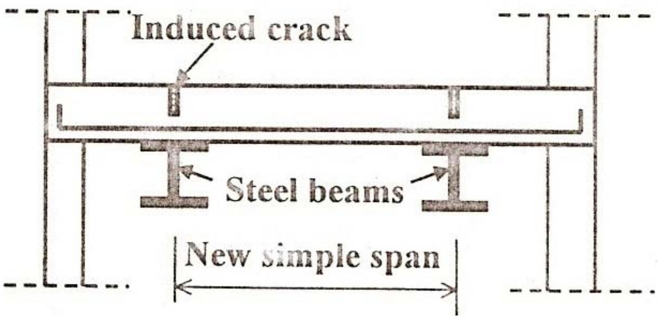
i. Strengthening using concrete overlays as shown in Fig. 3.21 (a)
ii. Strengthening using concrete under-lays as in Fig. 3.21 (b).
iii. Span shortening using steel beams such as in Fig. 3.21 (c).



(a) Concrete overlays



(b) Concrete under-lays



(c) Span shortening

Fig. 3.21: Strengthening of slabs [3].

3.4.4.6 Other methods for strengthening

Several other methods and techniques are used worldwide for strengthening of reinforced concrete structures. Among these methods the following can be listed [20]:

i. Strengthening with carbon fibers.
ii. Strengthening using externally bonded steel plates.
iii. Strengthening using external post-tensioning.

3.4.4.7 Electrochemical techniques

The electrochemical techniques used for stopping corrosion in concrete structures are [20]:

i. Cathodic Protection.
ii. Chloride Extraction.
iii. Re-alkalization.

All electrochemical maintenance methods have principles and practical details in common. The main differences are the amount of current flowing through the concrete and the duration of the treatment. The general set-up that is valid for all electrochemical methods is that by means of an external conductor, called the anode, a direct current is flowing through the concrete to the reinforcement which thereby is made to act as the cathode in an electrochemical cell. The final result of the current flow is to mitigate or stop the corrosion by depassivation of the rebars due to polarization of the reinforcement to a more negative potential, or by removing the aggressive ions (chloride) from the pores of the concrete or by reinstating the alkalinity of the pore solution [20].

REFERENCES

[1] Mohamed Ziara, **Urban Reconstruction**, N. Munier (ed.), Handbook on Urban Sustainability, PP 607-686, Published by Springer, 2007.

[2] C. Dave Gaughen, Joseph H. Brandon, **Overview Of Industry Guidance On Concrete Condition Assessment and Concrete Repair For Use Prior To Coating**, Special Publication SP-2085-SHR, NAVAL Facilities Engineering Service Center , Port Hueneme, California 93043-4370, June 2000.

[3] Mohamed Ziara, "**Structural Upgrading of RC Structures**", Seminar on rehabilitation of structures, Engineering Association, Gaza, Palestine, PP 78-110, 5-7 August, 2001.

[4] ICRI, International Concrete Repair Institute, **Concrete Repair Terminology**, http://www.icri.org, Visited on 20/7/2008, ConcreteRepairTerminology.pdf.

[5] Baldwin N.J.R, King E.S, **Field Studies Of The Effectiveness Of Concrete Repairs**, Phase1 Report: Desk study and literature review, Mott MacDonald Ltd for the Health and Safety Executive, Crown copyright 2003, First published 2003, ISBN 0 7176 2783 7.

[6] Sika, Construction Technology and Concepts Brochure, **Repair and Protection of Reinforced Concrete**, WP.07.04, http://www.ribaproductselector.com, visited on 17/08/2008.

[7] Mohamed Ziara, **Strengthening of Structures**, ENGC 6355 Course, IUG, 2005.

[8] S.L Karunakaran, **Handbook on Repair and Rehabilitation of RC Buildings**, published by Director General (works), Central Public Works Department, Government of India, New Delhi, 2002.

[9] The Concrete Repair Association (CRA), **The Route To A Successful Concrete Repair**, GN1, Reprint April 2001.

[10] K. Soudki, **Concrete Problems and Repair Techniques**, a seminar held at Professional Engineers Association, Beirut, Lebanon, February, 2001.

[11] ACI 207.3R-94, American Concrete Institute, **Practices for Evaluation of Concrete in Existing Massive Structures for Service Conditions**", Reported by ACI Committee 207, American Concrete Institute, MCP05, 2005.

[12] ACI 546R-04, American Concrete Institute, **Concrete Repair Guide**, Reported by ACI Committee 546, American Concrete Institute, MCP05, 2005.

[13] EM 1110-2-2002, Department of the Army U.S., **Engineering and Design-Evaluation and Repair of Concrete Structures**, Army Corps of Engineers, 30/06/1995.

[14] Portland Cement Association, PCA, Concrete Information، **Concrete Slabs Surface Defects: Causes, Prevention, and Repair**, 2001, IS-177-07.

[15] ACI 224.1R-93 (Re-approved 1998), American Concrete Institute, **Causes, Evaluation and Repair of Cracks in Concrete Structures,** Reported by ACI Committee 224, American Concrete Institute, MCP05, 2005.

[16] D.W.S Ho, **Durability of Concrete**, Edited by: W.f. Chen, J.y. Richard Liew, The Civil Engineering Handbook, 2nd ed. CRC Press LLC, 2003.

[17] ACI 302.1 R-04, American Concrete Institute, **Guide for Concrete Floor and Slab Construction**, Reported by ACI Committee 302, American Concrete Institute, MCP05, 2005.

[18] Portland Cement Association PCA web site, Concrete Technology, FAQS, **What causes efflorescence and how can it be avoided?,** http://www.cement.org, visited on 20/08/2008.

[19] ACI 201.1R-92 (Re-approved 1997), American Concrete Institute, **Guide for Making a Condition Survey of Concrete in Service**, reported by ACI Committee 201, American Concrete Institute, MCP05, 2005.

[20] REHABCON Manual, **Strategy for Maintenance and Rehabilitation in Concrete Structures**, EC DG ENTR-C-2 Innovation and SME Programme, June 2004.

[21] Five Star Products INC., **A Professional's Handbook on Grouting and Concrete Repair**, 2007.

[22] **Guide to Concrete Repair**, United States Department of Interior, Bureau of Reclamation, Technical Service Center, 1997.