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**CERTIFICATE**

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## **ABSTRACT**

Forensic Structural Engineering is a field of engineering which involves the study of structure and determining the causes of failure of structure. Forensic structural engineering is evolving in India into a designated field of professional practice of determining the causes of structural failures and identifying the parties responsible. The practice involves engineering investigations, rendering opinions and giving expert testimony in judicial proceedings if required. Whether they occur during construction or during their service lives, failures of constructed facilities are almost always followed by engineering investigations and resolution of claims. As the findings inevitably create claims of damage and often result in disputes and legal entanglements, the forensic structural engineer operates in an adversarial environment and therefore needs not only to be able to perform the necessary investigations but also to have an understanding of the basic concepts of the practice of forensic engineering.

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## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 GENERAL**

Engineering investigations of buildings, bridges, and other constructed facilities that fail or do not perform as intended, rendering opinions as to the causes of failure or underperformance, and giving testimony in judicial proceedings are fields of professional practice often referred to as forensic structural engineering. Forensic structural engineering is the application of engineering sciences for the investigation of failures or performance problems. Forensic structural engineering is a highly specialized field of engineering practice and thus, requires expert knowledge of engineering and legal procedures during structural failure investigation. The role of the forensic structural engineer, as an expert consultant, is to determine the cause(s) of failure of a constructed facility and to provide the technical bases upon which the responsibilities for the failure can be identified. During structural investigation forensic structural engineering services assess the damage to materials, products or structures and evaluate repair estimation. Failures result from a variety of causes involving both technical/physical problems and human error/procedural factors. Often the root causes of a failure or accident are difficult to isolate and quantify. The causes may be a combination of interrelated deficiencies. Things can go wrong anywhere along the planning–design–construction–service lives of a constructed facility.

## CHAPTER 2

### LITERATURE REVIEW

#### **2.1 N.Delatte and K.Carper “US and International Developments in Forensic Engineering and Education” 2010.**

Reviewed the development of Technical Council on Forensic Engineering (TCFE) in the US with particular emphasis on educational activities. Over the past three decades, the Technical Council on Forensic Engineering (TCFE) of the American Society of Civil Engineers (ASCE) has worked hard to establish and promote forensic engineering as a respected profession. The ultimate goal of forensic engineering is to improve quality and safety of constructed facilities. Considerable work has been done in the area of integrating failure case studies and forensics into graduate and undergraduate engineering education. In addition, international developments in forensic engineering are discussed. Many of the recent efforts of the Technical Council on Forensic Engineering been focused on outreach to other countries. The differing legal, educational, and professional licensure practices in other countries make these outreach efforts interesting and challenging.

#### **2.2 M.K.Pathan, S.W.Ali, S.Zubair, A.H.Najmi “A Forensic View to Structure’s Failure Analysis” 2015.**

Discussed the significance of chemical analysis for cement and its various mix products (i.e. concrete, mortar, etc.) in advocating the reasons of the failure. The analysis and estimation of different types of samples collected from the site of the failure, in forensic science laboratories requires high degree of skill and Expertise. Firstly Sampling of Cement, mortar, concrete is done then the method of analysis by various tests including testing and alternative method. From this analysis and test they get data which allow them to frame report regarding the cement percentage with acid insoluble and cement with non-cementitious material. By performing the chemical analysis of the samples collected from the scene of the failure of the structure, one can easily advocate the fact behind the failure precisely. Finally, the cement content determined by various method compared with the specifications laid by the relevant codes may form the basis for reason behind the failure.

### **2.3 J.G.M.Wood “Applying Forensic Investigations of Failures of Structural Performance” 2017**

The objective of this paper is to highlight the need to disseminate information to improve construction practice based on the consideration of the widespread instances of substandard performance where structures fall below the three design ideals— solid, useful, beautiful. Investigation of durability failures needs to be given priority, so we can develop a basis for appraising the safety of our decaying. Standard committees should compile and maintain a list and obtain full details of relevant failures to guide revisions to standards and guidance documents. They should also clearly state the limits of applicability.

### **2.4 Hamma-adama, Kouider “Causes of Building Failure and Collapse in Nigeria” 2017**

reveals that the frequency of building collapse in Nigeria is at an alarming rate and the impact is moderately major; substandard reinforcement, structural steel and cement used for the production of foundations, columns, beams and slabs are the main causes of building collapse (in descending order). It was gathered from the literatures that sub-standard building materials, faulty design as well as lack of proper supervision as the main causes of building failure and collapse in Nigeria. 90.9% over warmly agreed that sub-standard building materials is amongst the causes and also ranked three as the major materials (reinforcement steel, structural steel and cement) for failure.

## **CHAPTER 3**

### **FORENSIC STRUCTURAL ENGINEERING**

Forensic structural engineering is the application of engineering sciences for the investigation of failures or performance problems. Forensic structural engineering is a highly specialized field of engineering practice and thus, requires expert knowledge of engineering and legal procedures during structural failure investigation. From an engineering perspective, forensic engineering deals with the investigation and reconstruction of failure. From a legal perspective, forensic engineering is a fact finding mission to learn the most probable cause or causes of failures.

These cases and some of what can go wrong in them include the following, planning i.e. system concept, design i.e. concept, calculations and drafting, design–construction interface i.e. shop drawing detailing, drafting, review and approval construction i.e. erection, inspection and accident, in service i.e. misuse, overload, alteration, adjacent construction, deterioration i.e. lack of maintenance.

Failures are always the result of human action, which lie in one or more of the following i.e. negligence which means failure to properly analyze or detail the design or the disregard of codes and standards, incompetence that is failure to understand engineering principles or respect the technical limitations of materials or systems, oversight i.e. failure to follow design documents and safe construction practices, greed, shortcuts i.e. intentional disregard of industry requirements and safe practices, disorganization i.e. failure to establish a clear organization and define responsibilities of parties, miscommunication i.e. failure to establish and maintain lines of communication among the parties, misuse, abuse, neglect i.e. using the facility for purposes beyond its design intent or foregoing preventive maintenance.

The types of cases of failures that forensic engineering expert consultants/witnesses encounter can be categorized into three groups they are when a “condition” surfaced i.e. This is when some structural deficiency, such as possible overstressing, cracking, excessive deformation, objectionable vibrations, etc., is observed, when a failure or collapse occurred: This is when part or all of the structure has failed or collapsed, when dispute resolution or litigation is already in

progress. This is when the damage had already occurred sometime in the past, and the legal activities, such as preparation for trial in court, are underway.

In forensic engineering work, design codes and standards provide the baseline for the design requirements that were in effect at the time when the design was done, and they define the minimum level of performance that the failed structure should have met. Satisfying the governing code is a minimum requirement. Copies, especially old copies of design codes, standards and manuals are valuable references on a forensic engineer's bookshelf. During construction in the United States, inspectors of the US Government Office of Safety and Health Administration (OSHA) make unannounced visits to construction sites, issue violations when warranted and impose fines for violations of the so called OSHA Regulations. By act of Congress, OSHA is to investigate all construction failures where fatalities occur. OSHA's report opines on the innocence or culpability of the contractor(s) at the site; it does not address the designer's responsibilities. The OSHA Regulations and the OSHA report on the particular incident are the important documents for the forensic engineer to review in his or her engineering investigation and for opining on the responsibilities.

A forensic structural engineer is an authorized proficient engineer who has acquired information, aptitudes, and capacities through instruction, preparing, and involvement in the field of structural engineering to check, evaluate, examine and provide opinions, inferences and suggestions relating to a basic designing issue where something turned out badly, fizzled, was harmed, or did not execute as expected. Here are a few obligations of a typical forensic structural engineer they are provide bearing, coordination, arranging, and consummation of different engineering projects & investigations, communicate with customers to comprehend project needs, plan and define engineering programs & investigations and arrange a project staff as indicated by project prerequisites ,perform investigation and plan of the structural systems for a wide range of structures and materials utilizing different building codes, manage project deliverables and design as well as other design team associates, supervise the task of modelers and engineers, and direct task staff in planning contract documents like specifications & drawings, understand and track budgetary data identified with the venture. The essential target of any forensic engineering report is normally to introduce defensible inferences tending to worries of a specialized sort. These must be exhibited in a way which is promptly reasonable to the individuals who need to make use of

these conclusions. The group of onlookers may in this way be other specialized experts yet likely incorporate non-specialized people. Where a report might be utilized as a part of litigation, the reasonable beneficiaries will be non-specialized people. These might be lawyers or agents, and may at last be the trier of the fact, for example, a judge, jury individuals, or arbitrator.

### 3.1 Goals of Structural Failure Investigations

The goals of structural failure investigations is to determine the cause of failure. To compare statements by witnesses or injured parties with physical evidence. To ascertain whether an illegal or improper activity was causative. To assess damage to materials, products or structures and evaluate repair estimate.

### 3.2 Types of Structural Failures

Failure need not always mean that a structure collapses. It can make a structure deficient or dysfunctional in usage. It may even cause secondary adverse effects.

**Safe failure** which causes injury, death, or even risk to people, collapse of formwork during concrete placement Punching shear failure in flat slab concrete floor Trench collapse Slip and fall on wet floor.

**Functional failure** which causes compromise of intended usage, Excessive vibration of floor, Roof leaks, inadequate air conditioning, poor acoustics.

**Ancillary failure** which causes adverse effect on schedules, cost, or use that is delayed construction, unexpected foundation problems, unavailability of materials, strikes, natural disasters, etc.

According to Jack Janney (1986), the structural failure can be divided into structural distress that is an impairment of the strength or load response of a structure which may limit its use as intended, structural failure that is the reduction of the capability of a structural system or component to such a degree that it cannot safely serve its intended purpose, structural collapse that is gross movement of major members or a significant portion of a structural system manifested by the creation of rubble from breakage of the members themselves and elements supported by themselves.

Gerald Leonards (1992) defines “failure” as an unacceptable difference between expected and observed performance. This definition can be used to describe catastrophic failures as well as minor failures such as roof leaks. The ASCE Technical Council on Forensic Engineering has adopted the above definition provided by Gerald Leonards.

### 3.3 Causes of Structural Failures

Structural failure does not have to be a “catastrophic collapse”; it may be a “non conformity with design expectations” or a “deficient performance”. Collapse is usually attributed to inadequate strength and/or stability, while deficient performance or so-called serviceability problems, and is usually the result of abnormal deterioration, excessive deformation, and signs of distress. In short, failure may be characterized as the unacceptable difference between intended and actual performance.

**Negligence** that is failure to properly analyze or detail the design, or disregard codes and standards.

**Incompetence** that is failure to understand engineering principles or respect the technical limitations of materials or systems.

**Ignorance, Oversight** that is failure to follow design documents and safe construction practices

**Greed, Short cuts** that is intentional disregard of industry requirements and safe practices.

**Disorganization** that is failure to establish a clear organization and define roles and responsibilities of parties.

**Miscommunication** that is failure to establish and maintain lines of communication between parties.

**Misuse, Abuse, Neglect** that is using the facility for purposes beyond its intended or foregoing preventive maintenance.

### **3.4 Qualification of Forensic Structural Engineering**

For the qualification of forensic structural engineering they should be technical competency, they should have good knowledge of legal procedures, they should have detective skills, they should have effective oral and written communication, and they must be highly ethical standards.

### **3.5 Application of Forensic Structural Engineering**

Insurance companies use forensic engineers to prove liability or non-liability. Most engineering disasters (structural failures such as bridge and building collapses) are subject to forensic investigation by engineers experienced in forensic methods of investigation. Rail crashes, aviation accidents, and some automobile accidents are investigated by forensic engineers in particular where component failure is suspected.

## **CHAPTER 4**

### **METHODOLOGY ADOPTED**

The process of a forensic investigation of a failure and the activities of the expert consultant investigating the case may be coarsely outlined as first-response and preliminary assessment, development of investigation strategy, fact gathering and document review, and engineering analyses to determine cause(s) and responsibilities, reporting.

Previous investigations in this area of research were generally done in one of these three ways they are questionnaire survey, case study, and literature review based, the questionnaire design is based on literature findings. It is directed towards confirming/validating some lingering causes of building failure as identified in the literature review above such as poor or sub-standard building materials as well as exploring new dimensions yet unexplored by researchers in this area. It is aimed that the validation or otherwise be based on quantifiable evidence from constructions professionals. For damage assessment in construction failure broadly two types of test are carried out as Destructive test for example core sampling, drilled samples, steel sampling, pull-out test, Non-Destructive test for example Rebound Hammer test, Ultrasonic Pulse Velocity test, Cover Meter test, Half-Cell Potential Measurement test, Impact echo/pulse echo test, Ground Penetrating Radar test, Semi-Destructive test for example Concrete core test, Capo test, Windsor probe test, load test Theoretical methods like RCA,ECFC,MORT,SSAI. Damage assessment through methodical tests permits the engineer to determine with reasonable clarity, true causes of damage and to measure its extent in structure and also to decide appropriate corrective measures..

#### **4.1 Initiation of Failure Investigation**

The failure analysis process often involves: Interpretation of the failure location and service data, including on-site review. Examination of the parts to determine the failure mechanism(s) Engineering root cause, including design, fabrication, transportation, installation and service. The process involve establishing a preliminary, objectives and scope of work, checking on conflicts in interest, executing a contract agreement , establishing an investigative plan.

## **4.2 General Investigation Process**

Investigation is the process of gathering information about an accident, the resulting harm, possible legal liability of any party for having caused that harm, and potential sources of restorative payments owed to or collectible from others to finance recovery from that harm. The steps involved are definition of investigation objective, collection of background information and documents, initial site visit, formation of investigation plan and project, formulation of initial failure hypothesis, comprehensive document review, site investigation, field testing and sample collection, structural analysis and laboratory testing, revision of failure hypothesis and final conclusion and the report.

## CHAPTER 5

### CASE STUDY

The study was developing a forensic framework for failures in reinforced concrete buildings. The study was the failure of Abu Baker mosque, Jabalrai City, Palestine. This study aims at developing a forensic framework for conducting forensic evaluation of failures occurred in reinforced concrete structures; such framework would support engineers in assessing forensic structural failures. The development of this framework requires systemizing the stages and procedures of forensic investigations related to reinforced concrete buildings, connecting them with legal responsibilities and validating the developed framework. The study was conducted by Mohammed Arafa, Husam Wadi, Mamoum Alqedra (2018).

#### 5.1 Construction Details

The project was construction of a three stories mosque building with a basement area of 70 m<sup>2</sup>, the ground floor with an area 400 m<sup>2</sup> for the male prayers. The first floor is for the female prayers with an area of 200 m<sup>2</sup>. The building comprises also a 36m minaret, a main dome and several small domes. The management board of the project comprised a consulting supervision firm with a full-time site manager, site engineer, part-time electrical and mechanical engineer. In addition, the contractor was required to provide the required technical staff.

The shuttering of the reinforced concrete ribbed slab of the 8.5 m height first floor of the mosque was started as per the approved plan. The works were continuously inspected by the consulting firm staff and daily comments were given to the contractor. Having issued the “permission to cast” by the consulting site manager, the contractor started the casting process of the first floor reinforced concrete slab of the mosque. The process of casting was proceeding as planned and the dropped slab beams were first gradually filled up by concrete. Having completed the slab beams, the final stage of the casting process was approached, which included the casting of the topping layer of the ribbed slab. After completing about 75% of the topping layer of the slab, a sudden collapse of the supporting steel posts for about 200 m<sup>2</sup> of the casted slab. About 400 m<sup>2</sup> of the concrete slab was collapsed, one worker was lost and several casualties’ workers were resulted from this accident, in addition to large financial losses.

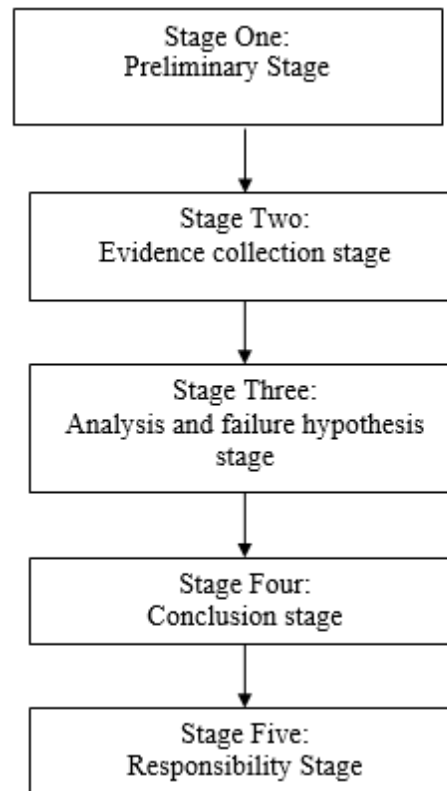


**Fig 5.1 Failure of Abu Baker mosque**

## **5.2 Forensic Framework**

The developed Forensic Structural framework would enable engineers in conducting forensic investigations for buildings. The developed FSF seeks to implement the best forensic practices within engineering investigation relevant to all types of failure occurred in reinforced concrete structures. An effective forensic framework should be simple and straightforward, represent all causes of failure in reinforced concrete structure and include corresponding legal responsibilities. Such framework requires well-experienced to assess conditions of the structure, identify the causes of damage and determine acts that lay the template for the failure, thereby enable Outlining major and minor responsibilities of the failure. The suggested framework, shown in

Figure, comprises five stages, as follows:



**Fig.5.2.Stages of forensic framework**

### **5.2.1 Preliminary stage**

In the preliminary stage, design and shop drawings, calculation sheets, daily instruction sheets, monthly reports, material orders and inspections, approved time schedule, soil reports, material test results, daily photos and any relevant documents were obtained and reviewed carefully.

### **5.2.2 Evidence Collection stage**

This stage comprised several steps and procedures, namely: visual inspection, eyewitness interview and sample collection.

### **5.2.2.1 Visual inspection**

The forensic team have conducted several visual inspection visits in order recognize the extent of commitment of the contractor with the approved work plan and technical specifications. Figure 2 presents some photos of the failure of the mosque.

### **5.2.2.2 Sample Collection**

The forensic team collected randomly several samples of the circular hollow steel posts (single size and double size posts) and the steel post connections. These samples were sent to an accredited local laboratory to obtain the outer diameter, inner diameter, wall thickness, uniformity of the thickness along the length, existence of corrosion, etc.

### **5.2.2.3 Eye Witness Interviews**

The forensic team interviewed the contractor engineer, supervision engineer, the shuttering subcontractor in order to take their statements regarding the cause of the failure.

#### **5.2.2.3.1 Statement of the Supervision Engineer**

The supervision engineer stated that after finishing all shuttering works including the supporting steel posts in two dimensions, the consulting site manager carried out a final inspection of the shuttering works and requested the contractor to replace some of the steel posts, provide more posts in certain locations, and increase the horizontal supports and extend it to reach a fixed positions. Afterwards, the consulting engineer approved the request for casting submitted by the contractor. The supervision site manager mentioned that after finishing about 70% of the slab area and when started casting the topping layer of the slab, the collapse suddenly occurred without noticing any deflection or deformation of the shuttering works.

#### **5.2.2.3.2 Contractor Engineer Statement**

The contractor engineer stated that they took all required technical and safety procedures for the shuttering works before the commencement of the casting process through installing additional supporting posts between the existing ones in the wide spaces between the steel posts. He also mentioned that the supporting steel posts were continuously inspected during the casting process.

He did not find any defect in these supporting posts. He added that the collapse occurred before the end of the casting process and happened suddenly with any indications.

#### **5.2.2.3.3 The shuttering Subcontractor**

The subcontractor stressed that all supporting system elements were safe, adequate and up to the standards for such works and he took all procedures and comments given by the consulting team. He added that he did not notice any failure or malfunction in the works. He mentioned that the same shuttering system was applied in similar projects and no problems were occurred.

### **5.2.3 Failure Hypotheses and Analysis Stage**

The forensic team has set four hypotheses for the failure in order to reach what was went wrong and identify the legal responsibilities. The following paragraphs present the details of these hypotheses and their analysis to reach the most likely cause of collapse.

#### **5.2.3.1 Deliberate Criminal Action.**

The Criminal Evidence Service conducted a technical criminal investigation to examine possible causes of the failure by examining the site, documenting the scene of the event, looking for evidence of any criminal suspicion by questioning the site guard and the office boy. They looked for evidence of any kind of explosions or tremors at the event site or near of the site.

The investigation, which was carried out by the Criminal Evidence Service, concluded that there was no intentional or unintentional criminal suspicion of the incident and concluded that no explosions or large vibrations occurred at or near the site. Consequently, the forensic team excluded this hypothesis.

#### **5.2.3.2 Inadequate Applied Supporting System**

The use of the single steel post support system is one of the most popular and widely used systems. This is due to the fact it is an easy-to use-system and the only available one in the Gaza Strip. This is system is limited to heights of up to 5 m. This limitation forced the contractors to install two or more of these posts on top of each other to achieve heights above 5 m. Such supporting system (more than one layer of posts) includes several weaknesses and risks that could cause problems,

for example the weak interconnection between these layers. In the current case, two supporting layers were installed to reach the required 8.5m height; each layer of support was about 4.25 m height.

The investigation, which carried out by the forensic team during the evidence collection stage, concluded that the contractor committed to the approved working plan and the technical specifications of the project. The contractor applied the approved spacing between the posts based on the calculation sheet of the floor loads and the bearing capacity of each steel post.

The calculations carried out by the forensic team revealed that the bearing capacity of each steel post is 1800 kg/m<sup>2</sup>; the applied load imposed on the floor is 1062 kg/m<sup>2</sup>. Based on applied load and the bearing capacity of the steel post, the design spacing between the posts should be not more than 90cm×90cm. The visual inspection revealed that the spacing between the posts ranged between 70cm to 90cm. The total load resulting from the main 60m wide dropped beam is 2092 kg/m<sup>2</sup>.

The revision of the approved work plan and the eyewitnesses indicated that three steel posts were installed along the width of the dropped beams with 40cm spacing between each of these three posts. This means that the three posts collectively receive  $0.40 \times 2092 \text{ kg/m}^2 = 837 \text{ kg}$ . Accordingly, each of the three steel posts receive one third of the 837 kg, which far less than the bearing capacity of the steel posts.

There was no indication of any defect in the results of the soil capacity. There were no cracks nor damages observed in the ground floor underneath the posts after removing the debris. All concrete test results of all structural elements were according to the technical specifications. The forensic team concluded that this hypothesis is not valid and consequently this hypothesis is excluded.

### **5.2.3.3 Existence of unseen defects in the used roof supports**

It is known that there are many steel components forming the single post roof supporting system. The main element of the system comprises a three inches hollow circular steel post with a thickness not less than 2.5mm. This steel post has also another circular steel post, which goes inside it; the inner pipe is used to adjust the height of the post. To ensure that the 3” hollow steel post is fixed with the inner post, threaded collar is provided and 12mm holes facing each other are made to

allow steel bars to pass through the outer and inner posts in order to connect them. The installation of such supporting posts requires high skills in assembling, fixing lacing etc. Therefore, the installation process could have many problems and defects are existence of unseen wear off, corrosion and rust in some of the used supporting posts. These defects could be difficult to discover due to the painting, variations in post wall thickness, which could not be easily, distinguish between by naked eye, existence of wear off in the threads of some of the posts. This could be very dangerous as it prevents the posts from performing properly, existence of buckling and/or deformation in the used steel posts, absence of the bottom post base, crookedness and misalignment of the steel posts and bad distribution of the posts according to the approved spaces and approved work plan. Therefore, the existence of such defects in the installed supporting posts and its components could be a valid cause of the failure.

From the samples collections, steel posts with thickness of 2.0 mm, 2.2mm and 2.3mm, were found. Some of the used steel posts suffer from wear off in the threads area and other posts have deep corrosions. These defects definitely reduced significantly the bearing capacity of these steel posts. Further, the verticality of several of the posts was not maintained, especially along the layers of the supporting system. In addition, some posts suffer from clear crookedness and buckling. Based on these findings, the forensic team concluded that this hypothesis is highly valid to be the cause of the failure

### **5.2.3.4 Analysis**

The casting of the top layer of the ripped slab was the final stage. However, this stage is considered one of the most important and most dangerous stage. This is because the casting process and the distribution of concrete on the roof requires a proper mechanism in order to avoid developing unbalanced weights during casting. Creating unbalanced weight could be a valid cause of the failure. As the eye witnesses stated that the failure occurred after about 75% of topping slab was completed.

Based on the eyewitnesses' statements, they stated that the contractor committed to provide and cast the concrete based on the approved method of statements of concrete casting. The casting was carried out gradually for the main dropped beams. Having completed the casting of the beams, the

contractor started casting the topping layer. The forensic team concluded that the applied casting process could be responsible for the failure through developing some unbalanced weights.

### **5.2.4 Case Conclusion**

In conclusion, the forensic team concluded that the main cause of failure would mainly be referred to the unseen defects in the used materials including the main supporting steel posts. In addition, the failure was triggered by the development of a state of unbalanced weights when casting of the topping layer started.

### **5.2.5 Responsibilities Assigning Stage.**

Based on the case conclusion that the main cause of collapse was due to defects in the used supporting steel posts. The installation and performance of such posts are of the major tasks of the contractor who should take the major responsibilities for any failure in these supporting posts. In addition, the consulting site manager takes a minor responsibility because he/she should have disapproved such material to be used. Therefore, the forensic team concluded that contractor and its insurance company should bear the legal and financial consequences of the collapse.

## **5.3 Conclusions**

The current study developed a forensic framework for conducting forensic structural evaluation of failures occurred in reinforced concrete structures; existence of such framework would assist engineers in investigating building failures. The framework outlines the procedures required to conduct the investigation for the causes of failures of reinforced concrete buildings and identify the legal responsibilities.

The established framework comprises five stages; each stage consists of several steps to contain as many factors and parameters involved in identifying failures and their causes. This five stages framework comprise preliminary stage, evidence collection stage, analysis of failure hypotheses stage, conclusion stage and responsibilities assigning stage. One of the main benefits of the developed framework is the fact that the legal responsibilities stage are connected to causes of failure through evidence based-facts. The current forensic framework was applied to local collapse case as a validation step. The application of the suggested framework to the local collapse case

proved that the framework was comprehensive and effective in reaching the causes of failure and assigning legal responsibilities in a systematic procedure.

## **CHAPTER 6**

### **CONCLUSIONS**

Forensic structural engineering is gaining recognition as a field of professional engineering practice in many parts of the world. At one time or another, nearly all engineering firms do forensic engineering work as part of their practice or as occasional service to their favored clients. Low quality of construction material is most common factors that lead building defects and failures. Poor workmanship by contractors, incompetent contractors, faulty construction, and non-compliance with specification/standards by developers/contractors, structural defects, defective design/structure are the common problems in field of construction. Poor risk management, budget overruns, poor communication management, schedule delays, poor estimation practice, cost flow difficulties, design discrepancies, inadequate project structure, lack of teamwork are also a threat to the construction industry.

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