CASE STUDIES ON FORENSIC STRUCTURAL ENGINEERING

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In loving appreciation of my dear family and friends

May God shower his blessing on you.

Love you forever...

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ABSTRACT

Forensic engineering is the application of engineering science to the investigation of failure or performance problem. This field of engineering has a big potential in Malaysia as more expertise is required to carry out forensic engineering investigation on failed civil infrastructure. This study involves detailed analysis of methodologies for forensic investigation from four case studies representing different types of structural forms and causes of failure. In order to analyse the case studies, the objectives of investigation of each case study had been derived. In addition, detailed analysis of the failure hypothesis, investigation approaches, causes of failure, modes of failure and application of engineering mechanics that explained the failure mechanism for each case study had also been carried out. The case studies have demonstrated that, although some specific aspects in the methodology may differ from one case to another, the basic element of the methodology remain the same for all cases and it also showed how the selection of appropriate testing methods and analytical techniques can help to confirm the finding and verify the failure hypothesis. The result in terms of comparison between case studies with their different unique features, testing techniques, analytical methods and engineering mechanics are presented in this study. Finally, based on the understanding and analyses of the different features of the case studies, a general guideline of methodology of forensic engineering investigation is proposed. This general methodology is applicable to all forensic engineering investigation to implement best practices in the conduct of forensic engineering investigation, but the specific activities will differ depending on the nature of the problem. Based on the general guideline, the investigators will know the general procedure of the investigation activities involved in the forensic structural investigation.

ABSTRAK

Kejuruteraan forensik merupakan penggunaan ilmu pengetahuan kejuruteraan untuk menyiasatkan kegagalan atau masalah prestasi sesuatu struktur. Bidang kejuruteraan ini mempunyai potensi yang tinggi di Malaysia memandangkan semakin banyak kepakaran digunakan untuk manjalankan penyiasatan kejuruteraan forensik pada civil infrastruktur. Kajian ini melibatkan dengan manganalisis methodologi penyiasatan forensik pada empat kes yang setiap kesnya menggambarkan perbezaan dari segi bentuk struktur dan sebab kegagalan. Untuk menganalisis kes-kes tersebut, objektif penyiasatan untuk setiap kes telah dibentukkan, proses penganalisisan yang dijalankan menfokuskan kepada hipotesis kegagalan, cara penyiasatan, sebab kegagalan, gaya kegagalan dan penggunaan mekanik kejuruteraan yang menjelaskan mekanisme kegagalan. Kes-kes yang disiasatkan menunjukkan bahawa walaupun setiap kes mempunyai aspek yang khusus dalam methodologi penyaisatan tetapi asas unsurnya bagi semua kes kekal sama, di samping itu, kes-kes tersebut juga menunjukkan bagaimana memilih cara ujikaji dan keadah analitis yang sesuai untuk membuktikan hipotesis kegagalan. Keputusan dalam perbandingan perbezaan ciri-ciri, cara ujikaji, kaedah analitis dan mekanik kejuruteraan bagi setiap kes ditunjukkan. Akhirnya, dengan kefahaman dan hasil penganalisisan terhadap kes-kes, satu garis panduan umum bagi penyiasatan kejuruteraan forensik diterbitkan. Garis panduan umum ini sesuai digunakan dalam semua penyiasatan kejuruteraan forensik dengan tujuan untuk melaksanakan amalan terbaik dalam penyiasatan kejuruteraan forensik. Dengan merujuk kepada garis panduan umum ini, ahli penyiasat akan tahu prosedur umum bagi aktiviti siasatan yang terlibat dalam penyiasatan kejuruteraan forensik.

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LIST OF SYMBOLS

P	-	Point load
kN	-	Kilo Newton
MN	-	Mega Newton
Ib	-	Pound
mPa	-	Mega Pascal
m	-	Metre
mm	-	Millimetre
ft	-	Feet
in	-	Inch
sec	-	Second
R	-	Reaction force
Q	-	Axial force per length
n	-	Number of the piles
kHz	-	Kilo hertz
T	-	High tensile Bar

CHAPTER 1

INTRODUCTION

1.1 Introduction

Forensic engineering is the application of the engineering sciences to the investigation of failures or performance problems. It is a highly specialized field of engineering practice requiring engineering expertise and knowledge of legal procedures. Forensic structural/civil engineers perform "autopsies" on components or full-sized buildings, bridges, and other engineered constructed facilities/infrastructure in order to determine the cause and extent of failure. A secondary purpose is to determine methods of repair, rehabilitation or replacement.

From an engineering perspective, forensic engineering deals with the investigation and reconstruction of failures in buildings, structures, facilities, vehicles, and other engineered systems. From a legal perspective, forensic engineering is a fact-finding mission to learn the most probable cause or causes of a failure.

In order for the forensic engineers to intelligently investigate the cause of a failure and subsequently to identify the parties responsible for it, they have to have an understanding of not only loads, strength and stability, but also of the business and practice of design and construction in order to know where, when, how, why and by whom a cause of failure can originate. They have to know, of course, how to conduct

the investigation appropriate to the case; they must be very familiar to investigation approach. Since nearly all structural deficiencies and failures create claims, disputes, and legal entanglements, forensic engineers need to have some familiarity with the relevant legal process and need to know how to work effectively with attorneys. Complete familiarity with the nature and consequences of loads, and of the critical characteristics and vulnerabilities of structures of different types and materials is the most basic requirement.

1.2 Research significance

Forensic Engineering is a specialised discipline which is relatively new and unfamiliar field to the public. Recently there is increasing number of structural failures which involved forensic investigation to assist legal proceedings related to litigation and damage. This field of engineering has a big potential in Malaysia as more expertise is required to carry out forensic engineering investigation on failed civil infrastructural.

There is a need to carry out studies on:

1) Best practices in methodologies for conducting forensic engineering investigation.
2) Analysis of case studies on structural failure case studies with engineering significance
3) Development and practice of guideline for forensic engineering investigation.

1.3 Scope and objectives of study

The study will involve analysis of four case studies on selected buildings which represent different types of structural forms and also different causes of failure. The study will focus on the methodologies and the applications of engineering mechanics involved in forensic engineering investigation.

The objectives of the study are:

a) To compare the forensic investigation methodologies of various failure cases.
b) To evaluate the application of engineering mechanics in forensic structural investigation.
c) To propose a general guideline on forensic structural investigation failure.

1.4 Methodology

Methodology of this study involves the following stages:

1) Identifying suitable case studies

Selection of suitable case studies covering variety of structures and forms of failures.

2) Analysis of selected cases studies

Analysis on the causes of failure, types of failure, modes of failure, approach on how the investigation are carried out and what the equipment are used in investigation.

3) Comparison of methodologies

Compare each selected cases study on its own methodologies of investigation.

4) Evaluate the use of engineering mechanics

Analyse the application of engineering mechanics to solve failure problems.

5) Propose a general guideline

A general guideline is obtained as outcome.

1.5 Content of the study

The dissertation is divided into 4 chapters as follow:

1) Chapter 1: Introduction – State out the background of the research, the objectives and the significance of carrying out the research.

2) Chapter 2: Literature Review – Introduction to forensic engineering and other literature study relevant to the study.

3) Chapter 3: Case Studies – Detailed analysis of the four selected case studies in order to understand their methodology of forensic engineering investigation, causes of failure, modes of failure and application of engineering mechanics to explain the failure mechanism.

4) Chapter 4: Analysis of Case Studies and Discussion – Comparison of the result of the case studies in terms of their methodology of forensic engineering investigation, testing techniques, analytical methods and application of engineering mechanics. A general guideline as an outcome is obtained.

5) Chapter 5: General Guideline on Structural Forensic Investigation – Detailed explanation about the general procedures of the activities involved in the structural forensic investigation.

References

American Society of Civil Engineers (1989). *Guidelines for failure Investigation.* New York, ASCE.

Bell, Glen (1985). *"Failure Information need in Civil Engineering," Reducing Failures of Engineered Facilities,* ASCE, New York.

Cuoco,Daniel (1992). "*Investigation of L'Ambiance Plaza Building Collapse." Journal of Performance of Constructed Facilities,* ASCE, November, 1992

Dov Kaminetzky (1991). *Design and Construction Failures, Lessons from forensic investigation.* McGraw. Hill. 29-36

Feld. Jacob (1968). *Construction failures.* New York, John wiley & Sons. 51-55

FitzSimons Neal and Vannoy Donald (1985). *" Notes on Statistics of Failures of Constructed works," Reducing Failures of Engineered Facilities,* ASCE, New York.

Heger, frank (1991). *"Public-Safety Issues in Collapse of L'Ambiance Plaza," Journal of Preformance of constructed facilities,* ASCE, May 1991.

Janney.Jack R.ed (1986). *Guide to Investigation of Structural Failure.* New York.ASCE. 12-20

K.C.G Ong, J.M.Lau (1997). Structural Failure durability and Retrofitting. Singapore Concrete Institute. 33-39

Kenneth L. Carper (1988). Forensic *Engineering*. Elsevier science. 190-226

Kenneth L. Carper (1997). *Construction Failure,*2nd ed. New York. John Wiley and Sons.

Leonards, Gerald (1982). *"Investigations of Failures," Journal of the Goetechnical Engineering Division,* ASCE, Vol.108, No.GT2, February, 1982. 187-246

Levy Matthys and Salvodori Mario (1992). *Why building Fall Down: How Structures Fail.* W.W.Norton, New York.

M.A.Mansur, K.H.Tan, P.Paramasivam (1993). *Structual Failure Durability and Retrofitting,* Singapore Concrete Institute. 31-38

Peter Rhys Lewis, Ken Reynolds, Colin Gagg (2004). *Forensic Material Engineering – Case Studies,* CRC PRESS. 61

Rachel Martin and Norbert J. Delatte (2000), *" Another Look at the L'Ambiance Plaza Collapse," Journal of Performance and Constructed Facility.* ASCE, November, 2000. 160-165

Robert T, Ratay (2000). *Forensic Structural Engineering Handbook.* McGraw. Hill. 4.14, 6.1-6.30

Roddis,W.M (1993). *"Structural failures and Engineering Ethics," Journal of Structural Engineering,* ASCE, May 1993.

Specter, Marvin (1993). *National Academy of forensic Engineers*. NAFE. 5-6

The American Heritage Dictionary of the English Language, 3rd ed. New York, Houghton Mifflin co.,1992

The Malaysian Law Journal (2003). *Steven Phoa Ching Loon & ORS V Highland Properties SDN BHD & ORS.* LexisNexis Asia(a division of Reed Elsevier (S) Pte Ltd). 370-433

Thornton, Charles (1985). *"Failure Statistics Categorized by Cause and Generic Class," Reducing Failures of Engineered Facilities.* ASCE, New York.

Tomasz Wierzbicki, Norman Jones (1988). *Structural Faiulre,* A Wiley- Interscience Publication, John Wiley & Sons. 19

W.H.Mosley, J.H.Bungey and R.Hulse (1999). *Reinforced Concrete Design.* J.W. Arrowsmith Ltd. Bristol. 265-268

William H.Lewis (1978). *Prevention of structural failure – The role of NDT, Facture mechanics and Failure analysis.* Material/ Metalworking Technology Series American Society for Metal. 49