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**APPLICATIONS OF ENGINEERING THEORIES IN
STRUCTURAL FORENSIC INVESTIGATION**

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Civil-Structure)

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I declare that this thesis entitled "*Application of Engineering Theories in Structural Forensic Investigation*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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To my beloved mother and father

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IN THE NAME OF ALLAH THE MOST GRACIOUS AND MERCIFUL

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ABSTRACT

Structures fail due to various causes and reasons. Over the years many hypotheses and engineering theories have been used to investigate these failures. Boundary condition and load path mechanism theory are among the engineering theories that have been applied in the structural forensic investigation of failed civil engineering infrastructures. These theories were derived from the theory of solid mechanics or strength of materials which deal with the study of forces and their effects on bodies that are in rest (static) or in motion (dynamic). In this paper, two selected case studies (static) involving structure failure in terms of collapse were analysed. With reference to the original forensic engineering investigation report, the case studies were analysed in terms of the methodology of investigation, application of engineering theories and approach in developing failure hypothesis. From this study, the qualitative analysis of the latest case of structural failures in Malaysia was compiled for academic purpose and the investigation techniques in structural forensic failure in practice were documented for use as reference. From this analysis, the general guideline on the use of engineering theories in forensic engineering is proposed.

ABSTRAK

Kegagalan struktur berpunca daripada pelbagai sebab. Biasanya untuk menyiasat kegagalan tersebut, pelbagai hipotesis dan teori kejuruteraan telah digunakan. Antara teori kejuruteraan yang digunakan dalam penyiasatan kegagalan infrastruktur kejuruteraan adalah had sempadan dan mekanisma aliran beban. Teori ini adalah diasaskan dari teori mekanik pepejal yang melibatkan kajian daya dan kesannya kepada jasad dalam keadaan rehat (statik) atau dalam keadaan bergerak (dinamik). Dalam kertas projek ini, dua kajian kes (statik) telah dipilih untuk dikaji dari segi metodologi penyiasatan, penggunaan teori kejuruteraan dan pendekatan yang diambil dalam merangka hipotesis kegagalan. Dari kajian ini, analisis kualitatif bagi kejadian kegagalan struktur terkini di Malaysia dikumpulkan untuk tujuan akademik dan teknik penyiasatan kegagalan struktur terkini didokumentasi untuk kegunaan sebagai rujukan. Dari analisis ini juga, garis panduan umum bagi penggunaan teori kejuruteraan dalam penyiasatan kegagalan struktur dicadangkan.

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LIST OF ABBREVIATIONS

B	–	Bernoulli or Beam region
D	–	Disturbed or Discontinuity region
FS	–	Factor of Safety
MS	–	Margin of Safety
R	–	Applied Stress/Resistance
STM	–	The Strut-and-Tie model
UTS	–	Ultimate Force/Stress
Q	–	Structural action/Load effect

LIST OF SYMBOLS

A	–	Area
E	–	Young's Modulus
F_x, F_y, F_z	–	Force in x, y and z-direction
F	–	Force
l_0	–	Initial length
l_1	–	Length after deformation
M	–	Moment
M_x, M_y, M_z	–	Moment in x, y and z-direction
N	–	Axial Force
P_y	–	Design Strength
ΣF	–	Sum of all forces
ΣM	–	Sum of all moments
T	–	Torsion
V	–	Shear force
σ	–	Stress
ε	–	Strain
γ	–	load factor
Φ	–	resistance factor

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CHAPTER 1

INTRODUCTION

Forensic structural engineering is often referred as the engineering investigation and determination of the causes of structural failures of buildings, bridges and other constructed facilities. Structural failure does not have to be a ‘catastrophic collapse’; it may be ‘non-conformity with design expectation’ or ‘deficient performance’. Collapse is usually attributed to inadequate strength and/or stability; deficient performance, or so-called serviceability problems, is usually the result of abnormal deterioration, excessive deformation, and signs of distress. In short, structural failure may be characterized as the unacceptable difference between intended and actual structural performance.

1.1. Introduction

Failure of constructed facilities may carry a considerable price tag for structural replacement/rehabilitation and loss of business or life. Successfully diagnosing the probable cause of failure, assessing its consequences, and presenting the findings convincingly and in a mutually understandable manner are vital to the

process. Therefore, to attain such a reliable result, it is important to use suitable and correct methods of investigation of the failure.

In investigating structural failure due to deficiencies in structural system, the application of engineering theories is essential. These deficiencies are in terms of insufficient strength, stiffness and stability or combination of these parameters. Each parameter can be determined using stress analysis which concerned with the behaviour of bodies under load. The basic equilibrium analysis tool used to determine forces' acting on the body is the free body diagram. The concept is, if the diagram is not drawn correctly during design stage, the forces cannot be calculated accurately and the design may be unsafe. This will lead to failure of the structure. In addition, prediction of loading and determination of load path are also important in achieving safe design. Correct detailing and good inspection during construction also contribute to safe structure.

1.2. Significance of Study

Many cases of structure failure are investigated by applying various concepts in engineering theories. The approaches of investigation are usually different from one case to another. In order to study this, data compilation should be done and the lessons learned from failures of the structures should be reviewed. And for formulating a general guideline on the use of engineering theories in structural forensic investigation, the analysis of the engineering theories as well as the study of methodologies are necessary.

1.3. Objectives and Scope of Study

This study will focus on the investigation of structural failures due to deficiencies in strength, stiffness and stability caused by design and construction error. And the objectives of the study are:

- a) To compile data and review on lessons learned from failures of various civil engineering structures.
- b) To study the methodologies used in forensic engineering investigation.
- c) To analyse the applicability of various engineering theories (static analysis) in structural forensic investigation of failed structures.
- d) To provide a general guideline on the use of engineering theories in structural forensic investigation.

1.4. Case Study

A case study involving two forensic engineering investigation projects will be carried out to demonstrate the applicability of the engineering theories in assisting the failure analysis. Each case study will be analysed in terms of the following aspects;

- (a) the methodology for the investigation
- (b) the use of engineering mechanics in the failure analysis
- (c) the approach in developing failure hypothesis

The selected case study to be analysed are as follows;

- (a) Case Study 1 : The collapse of roof truss in School Project
- (b) Case Study 2 : The collapse of the Club House Project