© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJSCET

http://penerbit.uthm.edu.my/ojs/index.php/ijscet
ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Education in the Field of Forensic Engineering

Kousay Al-Sanjery[1], Kong Fah Tee[2], Horng Hean Tee[1]*

[1]SEGi University,
Kota Damansara, 47810, MALAYSIA

[2]University of Greenwich,
Kent, ME4 4TB, UNITED KINGDOM

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2020.11.02.003
Received 30 July 2020; Accepted 30 August 2020; Available online 02 September 2020

Abstract: The profession of forensic engineering has been used in investigations for causes of failure in various engineering cases and used when engineers require to give testimony in judicial proceedings. Forensic engineering has become a field of professional practice of its own; criteria and procedural methods have been proposed in the United States, UK and Europe. Many professionals and engineering institutions have venture in this field and set basic principles to establish a platform for going forward. This paper will cover the topics in design-construction process, design codes and standards, construction safety codes, standards and regulations, the first steps after failure, legal concerns after a failure, standard of care and case studies. It is hoped that the paper will enlighten the scope and details of the forensic engineering discipline which can be used as a tool for a failure knowledge base for engineering education and learning outcomes.

Keywords: Forensic engineering, Education, Structural failure, Design, Construction, Safety

1. Introduction

Forensic engineering involves the use of engineering principles and knowledge to determine the cause of the resulting engineering failure. Failures in the construction industry are not just accidents; they could also be due to the results arising from human errors originating from oversight, carelessness, ignorance or greed. The advancement of design sophistication and construction methodology causes the proliferation of the construction failure. Investigations into a failure give unique lessons and understanding of what went wrong and how the process of design and construction should be dealt with. It is nowadays especially in local setting that very commonly engineers rely heavily on computers due to a very competitive engineering environment. Designs are needed to be produced as promptly as possible and during the process of speeding up the engineering designs, there is always a possible source of human error.

Engineers who are involved in the investigations of engineering failure are known as forensic engineers, should have on their background (Day, 1998; Ratay, 2000), a good education in relevant engineering discipline and its related subjects; years or even decades of experience in analysis, design construction, testing, inspection, and trouble-shooting; an understanding of the design-construction process; comprehension of legal implications; good communication skills; a knack for problem solving; a strong sense of ethics; self-confidence without arrogance; and a high level of intellectual sophistication. For sure some of these traits can be learned but most are ingrained, however it is the authors' experience that engineering students are more interested and keener to learn from practical approaches like actual or real-life case studies of some failures.

*Corresponding author: teehornghean@segi.edu.my

The practice of forensic engineering comprises professional engineering, legal commitments and ethical principles, construction and theory. Therefore, in the authors' opinion, it would be very beneficial to propose forensic engineering as independent discipline or to be incorporated in a coursework to undergraduate and/or postgraduate engineering students or indeed in continuing education. This will indeed satisfy some basic requirements of outcome-based education followed by most higher education institutions worldwide. As such forensic engineering will not only be an open-ended exercise but also an example for complex engineering problems which are stipulated in most of the recent version of the outcome-based education required by various Ministries of Higher Education to accredit any engineering program. In addition, forensic engineering can cover all domains of learning taxonomy including cognitive, affective and psychomotor domains. Furthermore, forensic engineering exercise can be assessed using the rating given in a respective rubric to satisfy course and program outcomes as requested by the Engineering Accreditation Council. Equally important is the link between university and the industry, whereby consultant, engineers, and contractors bring their case studies and experience to the students.

A lot of work needs to be done for the preparation of the course outline and respective details before it can be well incorporated in final year undergraduate projects. Since it is directly linked with the industry, it is expected that learning outcomes of this course will enable graduates to absorb more the dimensions of the industrial engineering practice. This will give students good technical background to share with other professionals and give better engineering service to the society. The present paper highlights the main topics proposed for the course outline with some introduction on the contents of each topic. Indeed, some topics will be in a forensic, and exploratory or investigative format. Example on this, is looking into a project history records whether satisfying safety or certain design requirements. The expectation and the outcome of this exercise make the students appreciate how much important these requirements are and to what extend each of them contribute to the failure and/or to accountability. The main topics discussed in this paper are design-construction process, design codes and standards, construction safety codes, standards, and regulations, the first steps after a failure, legal concerns after a failure, standard of care, and case studies. The issues of solving construction disputes and taking the stand/or witness in a court of law have also been addressed.

2. Design construction process, codes, standards and regulations

This item meant to discuss and review the sequence of events of a project from its design concept through the construction stage. It is intended to state the role and responsibilities of engineers in the design and construction process toward the common goal shared by the owner and the design professional, a quality project designed for its intended use and constructed within the budget and time restraints. The main topics covered under this title are drawings and specifications, checklists, inspection and testing, project delivery methods, documents at the construction site, review of project history and approval, acceptance, and certifications. Codes and standard requirements are important elements to be considered in the evaluation process after failure.

Therefore, the engineer concerned must be familiar with the provisions as well as the intent, and in some cases the history of the governing code or standard. In this regard, precaution must be considered in three major issues, these are variability in strength of materials between design and actual; variability of live and environmental loads including wind, earthquake, fire, flood and explosion; and consequences of failure and the setting of an acceptable factor of safety for a particular class of structure. In this regard, reliability management and probability of failure in choosing loads and materials safety factors for a particular type of structure must be considered. As an example, the European Code of Practice EN 206-1 and EN1992-1-1 together with EN1990 provide recommendations based on statistical approach to estimate the probability of failure and to derive a save reliability index. Accordingly, this approach should be used especially for important buildings such as building of high consequences of failure (British Standards Institution, 2002; Teplý *et. al*, 2005; Mahmoodian *et. al*, 2012; Tee & Pesinis, 2017).

Many failures and accidents are often related to construction, as most of them occur on site during the construction process. Therefore, engineers must be familiar with the codes, standards, regulations and practices that must be followed in the construction industry. Construction of all structures is governed by one or more safety standards. Most notable among them are the standards promulgated by the Occupational Safety and Health Administration (OSHA), U.S. Department of Labour, and the standards adopted by the American National Standards Institute (ANSI). The OSHA has stipulated more than one hundred construction standard categories related to physical hazards. The ANSI has adopted more than twenty standards relating to construction and more than 14 standards are in the development stage of construction. In addition, there are a number of recommended safe practices, guides, and manuals published by trade associations, manufacturer engineering associations, and other government agencies (ASCE Task Committee on Structural Safety, 1972; Office of the Federal Registrar National Archives and Record Administration, 2014). Incidents at construction sites occur through either construction errors or design deficiencies. A majority of incidents however are due to disregard of safety regulations, engineering over-sight, poor planning and lack of training on the part of workers. Another major cause is inappropriate shortcuts taken in haste to meet completion dates.

3. The first steps after a failure

Failures always occur suddenly and to the surprise of every person in contact with the project. The activities immediately following a collapse profoundly influence the success of subsequent technical investigation and may well prevent further damage or even the loss of life. It is of paramount importance to act quickly, objectively, and more importantly to be present at site, maybe within hours of the failure, to have a proper plan of action and to start immediately the investigative works.

Late or slow response or reactions to the failure may cause many evidences of perishable nature and issues and clues related to the failure not in its original form which will eventually jeopardize a proper and comprehensive investigation of the failure. In summary the following points must be considered:

• **Safety of the failed structure from further damage** – precautionary measures must be taken to ensure that any personnel doing investigative works near or under the structure do not result in a danger to them

• **Preserve highly perishable evidences –** any evidences obtained from the said site must be in such a manner that these evidences are not damaged or in any way may affect the investigative works which will eventually be continued at the lab or the office.

• Capture the configuration of collapse – if at all possible, as detailed as possible sequence of collapse should be verified so as to aid in the investigative works.

• Reserve samples for failed and un-failed components – proper samples taken whether failed or un-failed should be properly kept as it may be of further use at a later stage.

• Make sure of high-quality documentation of field notes, photographs and video – it is proper to ensure that high-quality documentation and also all forms of paperwork including digital information be of that state in order to avoid any doubts when the these are reviewed later on.

• **Conduct interviews** with related persons (eyewitnesses, workers, and persons with relevant project knowledge) as soon as possible – while the incident is still fresh, eyewitnesses and any personnel involved during the failure should be interviewed.

• **Ask for project documents** gathering that include design drawings, specifications, boring logs, calculations, shop drawings, submittal logs, inspection reports, daily reports, test reports and minutes of meetings and correspondences.

4. Legal concerns after a failure

Regardless of whether a failure is a major or a minor one, there are significant legal issues that need to be carefully considered by all parties involved with the failed element or elements of the project. The main purpose here is to highlight some of the most critical legal issues in failure analysis and investigation. This will help in identifying liability and the right to claim for each party. However, one should keep in mind that there is no "bright line" distinction between legal and technical liability issues associated with a failure, as they are both linked together. The legal and technical team who are investigating a failure must determine whether the cause of failure is due to technical error, procedural error, events beyond the reasonable control of any party, and also whether materials failure, workmanship, or any other external factors. In addition, the team must determine the role and consequently accountability of each party related to the failure.

This is why legal and technical teams must be interwoven from the outset of any investigation. An early legal concern, that should be considered, especially by project owner is to determine whether insurance covers the failure. There might be so many controversial issues on whether insurance will cover part or all loss including the cost of remedying the failure. Troublesome issues often include applicable exclusions, the amount of the policy deductible, waivers of subrogation against contractors or design professional and notice provisions within the policy.

After all facts and positions of the parties are understood, several theories of liability can be used to sue and find a potentially liable party responsible for a construction failure. This would require understanding and investigation into the legal framework of the failure. This includes:

• Liability associated with the failure, the three most common of theories are Contract-based liability, Tort-based liability, Strict liability and indemnity
• Contractual limitations of liability
• Applicable statutes of limitations and statutes of repose.

The construction industry has very often followed other ways and means to resolve dispute. These processes, which advisory arbitration panels, mediation, and dispute review boards, involve the use of third-party neutrals to assist the parties in understanding the facts related to the failure and in determining an appropriate way of resolving the accountability of the parties. When all means attempted failed to resolve the issues and to bring the two parties to an agreement, then one of the parties will refer the case to a court of law.

Normally the parties involved are the loss adjusters, the insurance company, the defendant lawyer and the forensic engineer. In this court, the report of the forensic engineer will be in question and therefore the forensic engineer has to take the stand to defend his report and to present his findings. At this point in time the credibility of the report in terms of technicalities, well-documented facts and sound reasoning are being investigated. The lawyer of the accuser accompanied by a technical professional person will have the first session by interrogating the forensic engineer regarding the claimed issues proposed by the forensic engineer's report.

The main issue of interrogating is to discredit the report and/or the credibility of the forensic engineer through the following:

- check on the forensic engineer to be a professional and a member of local professional bodies and have a good experience in the main discipline of the case.
- check on the report for any discrepancies including photos, statements in the report and by others.
- check thoroughly on the statements of the report.
- check on the scientific terminology used in the repot.
- check on confidentiality of the forensic engineer.

Often in investigation, performance of structural engineer is called into question. He/she may be accused of professional negligence, which means failure to possess and use the skill of a normally competent practitioner. If that is the question, an expert testimony is required to:

- Define the skill possessed by normally competent practitioners
- Come to an opinion whether the defendant's structural engineer conforms to an acceptable level.

Tort laws address circumstances where one person's behaviour injures another regardless of whether that behaviour is subject to criminal law penalties, such as when mistakes are made, or accidents happen. These laws require us to behave reasonably as individuals and as structural engineers, to exercise an adequate degree of care.

One of the important parts of the course outlines is to provide case studies of failures, and then for the students to investigate the potential causes of failure, define the standard of care of respective engineer and eventually to determine accountability.

5. Outcome based education (OBE)

As recommended by the International Engineering Alliance, problem analysis and investigation are important graduate attributes for all engineering graduates related to the Washington Accord Signatory countries. Respective assessment of students should address the three domains of learning, these are cognitive, affective and psychomotor which are related to program outputs. The learning taxonomy domains stipulated in the OBE targeting the program outcomes are cognitive domain, affective domain and psychomotor domain. Each of these composes various categories ranged from basic to an advanced level of learning outcome. Assessment of the students are based on their achievement of program outputs linked to theses taxonomy levels and respective course outcomes specified for each topic. Aspects of the field forensic engineering are complementary to the outcome-based educational approach, as this field requires investigative post-failure analysis.

Often, conventional tertiary engineering education emphasizes on proper design with limited exposure to post-failure analysis. Therefore, it addresses more on the cognitive and psychomotor domains rather than on the affective domain. On the other hand, forensic engineering addresses all three domains, more importantly, the affective domain. It plays an important role in establishing the ethics and responsibility of a graduate engineer. Exposure to failed structures and the consequent loss of life and economy due to the failure, imbues the sense of responsibility that would be a valuable asset when the students graduate and serve the industry and society. The Engineering Accreditation Council and Accreditation Board for Engineering and Technology set up program outputs, as accreditation criteria, which consist of twelve points. These criteria are to be employed in the assessment of the student performance. Two main program outcome criteria referred to in these program outputs, are open-ended exercise and complex engineering problem.

5.1 Open-ended Exercise

In the open-ended style, the problem may have multiple solutions and there is no best way of solving the problem. An exercise on this was simulated on laboratory experiments where experiments were performed by changing from an expository type of instruction style to an open-ended experiment. This approach was carried out particularly in the field of concrete mix design where the theory of design mix has not been taught in the classroom and the students request-ed to develop experimentally high strength concrete (Haron, *et al*, 2013; Rahman *et. al*, 2010).

It was concluded that the open-ended experiment increased the independent learning among students by giving them a platform to be innovative and creative in designing and executing their own experiments. Other practices have also revealed that open-ended experiments led the students to understand the concept of the experiment better than with the traditional way (Land, 2000; Berg, Bergendal & Lunuberg, 2003). The current practice adopting this concept is by giving the students a design problem which can have more than one solution, for example, in reinforced concrete design, the students were given a plan of a building then they designed based on their assumed layout and soil properties and made a comparison for a minimum of two options with regard to ease of construction, economy and safety.

Forensic engineering or investigating failure case directly links to open ended problem since:

- There could be more than one reasons to cause the failure as very often one reason may not be evident.

• It is required to choose certain experiments to verify properties of materials or behaviour of structure.
• It is required to understand fully the problem related to design and construction environment.

An example would be the collapse of the retaining wall as shown in Fig. 1. Since there are a few factors that led to the failure of the retaining wall, it would be beneficial for students to be able to investigate further in open-ended exercise type questions. This form of question will not only aid students to be more analytical but will also enable the students to apply engineering principles from different subject matters such as mechanics of materials, reinforced concrete design, foundation design and construction. The person facilitating the course must be very well versed or be the Professional Engineer involved in the project so that he knows the details such as material used (Fig. 2), specifications, structural system, etc. of the project involved and provide valuable feedbacks to the students.

Fig. 1 (a) - 100m Long Retaining Wall Failure During Construction to be Used as Open-Ended Exercise

Fig. 2 - Carrying Measurements with Samples taken from the Failed Retaining Wall

5.2 Complex Engineering Problem

The term complex engineering problem has been addressed in many of the program outcome criteria set by Engineering Accreditation Council, although the full definition of the term is not fully detailed. However, a complex engineering problem can indicate that the problem consists of more than one engineering discipline and/or profession and have more than one requirement to satisfy safety, economy and ease of construction. In fact, this definition applies to most of common problems in the engineering profession field.

As it is always and very common that engineering problem or failure case could be due to various interrelated reasons of safety, economy and ease of construction. Not much work or examples have been focused on in the literature with this regard and how this can be related to education. Forensic engineering can well simulate a complex engineering problem:

- The problem has many faces which need to be investigated
- Must understand all technical design and construction procedure
- Understand the design and construction management
- Understand the legal aspects and responsibilities of various parties which could not be well addressed in traditional teaching
- Decide whether the engineer of record has breached the standard of care anticipated as a professional engineer

6. Conclusion

The various topics mentioned in this paper can well be formulated and detailed to form a course outline with specified objectives and learning outcomes. The objectives are basically to equip graduate engineers with the methods, procedures, and tools to be used into the exercise of carrying out investigation of an engineering project failure. Furthermore, the learning outcomes basically are to give engineers a wider scope of work and deep technical vision to deal with and also to manage a crisis. However, to achieve these targets, and to satisfy fully the course objectives, a continuous link and contribution by Professional Engineers from the industry is very important and must be maintained, without which the course cannot be a success.

It would be hoped that with this course, young graduates are more well-equipped with the knowledge of Forensic Engineering. Not only will this benefit the young graduates in the sense that they will be more analytical and inquisitive on matters pertaining on how the failure of a structure for instance, occurred but however, this will also in general benefit the public because indirectly, since young graduates are trained on the consequences of a real life project failure, young graduates in their execution of their engineering design, will be more cautious and careful.

In order for the introduction of this module to be successful, besides the participation of industry Professional Engineers, the Board of Engineers can also assist in providing real life examples on how a particular project failed for students to investigate.

Acknowledgement

Author’s would like to thank you to SEGi University.

References

ASCE Task Committee on Structural Safety (1972). Structural safety - A literature review. Journal of the Structural Division, ASCE, 98, 845-884

Berg, C. A. R., Bergendahl, V. C. B., Lundberg, B., & Tibell, L. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. International Journal of Science Education, 25(3), 351-372

British Standards Institution. (2002) Eurocode – Basis of structural design. London: BS EN 1990

Day, R.W. (1998). Forensic geotechnical and foundation engineering. New York: McGraw Hill

Haron, Z., Mohammad, S., & Sam, A. R. (2013). The Implementation of an open-ended experiment in the civil engineering laboratory. Procedia-Social and Behavioral Sciences, 102, 548-559

Land, S. M. (2000). Cognitive requirements for learning with open-ended learning environments. Educational Technology Research and Development, 48(3), 61-78

Mahmoodian, M., Alani, A.M. & Tee, K.F. (2012) Stochastic failure analysis of the gusset plates in the Mississippi river bridge. International Journal of Forensic Engineering, 1(2), 153-166

Office of the Federal Registrar National Archives and Record Administration (2014). Code of federal regulations, Title 29, Part 1926. Labor, USA

Rahman, N. A., Kofli, N. T., Takriff, M. S., & Abdullah, S. R. S. (2011). Comparative study between open ended laboratory and traditional laboratory. In 2011 IEEE Global Engineering Education Conference (EDUCON) 40-44

Ratay, R.T. (2000). Forensic Structural Engineering HandBook. New York: McGraw Hill

Tee, K. F. & Pesinis, K. (2017). Reliability prediction for corroding natural gas pipelines. Tunneling and Underground Space Technology, 65, 91-105

Teplý, B., Keršner, Z., Rovnaník, P. & Chromá, (2005). Durability vs. reliability of RC structures. 10DBMC International Conférence on Durability of Building Materials and Components, Lyon, France