THE STRUCTURAL ENGINEER AS EXPERT WITNESS – FORENSICS AND DESIGN[1]

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This paper discusses how expert witness services can be improved in construction disputes where the determination of the cause of structural failures is critical. It examines some of the common ways structural experts fail to provide quality services, before focusing on an issue particular to causation investigations – a lack of forensic expertise and experience on the part of the expert.

The paper introduces forensic structural engineering and its history, examines the different roles played by forensic expertise and design expertise in legal disputes, illustrates how forensic expertise is ideally suited to determining causation, and concludes with practical guidance for legal teams to ensure expert witnesses approach their brief to determine causation in a manner that is independent, transparent, and forensically sound.

Introduction

In construction disputes involving structural failures, defects, or non-performance, the appointment of structural engineers as independent expert witnesses to determine the cause of the failure is a common occurrence. The experts are not only required to have appropriate technical expertise, but are also expected to approach their investigations in a manner that is forensically sound. When it is considered that the performance of expert witnesses, both in and out of the courtroom, can have a significant bearing on dispute outcomes, ensuring the experts can perform their duties effectively, efficiently, and independently is of paramount importance.

Discussions with legal professionals suggest that, while there are some engineers providing quality forensic structural engineering services, there is considerable room for improvement in the expert witness services provided by the wider engineering profession. The issue is rarely a lack of technical expertise, but typically relates to insufficient knowledge of legal requirements and processes, poor verbal and written communication skills, an inability to maintain independence, and poor performance in the face of adversarial cross-examination, all of which compromise an expert's ability to provide clear, independent, and evidence-based opinions. While these issues are common,

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there is another issue particular to causation investigations that should be considered – namely, a lack of forensic expertise and experience on the part of the expert witness.

Forensic expertise plays a critical role in determining the cause of engineering failures, yet many investigations are routinely undertaken by experts lacking this expertise, with little appreciation or experience in the approaches and processes necessary for the cause of failure to be successfully determined. This paper introduces forensic structural engineering and discusses its development as a specialist discipline in the U.S. over the past 30 years. The significant differences between the forensic process and the process more commonly used by professional engineers – the design process - are examined, and the paper concludes by providing practical guidance for legal teams to assist structural engineers improve the quality of expert witness services.

Forensic structural engineering

The role of the forensic structural engineer is to identify and communicate the cause of structural failure, and in some situations but not all, provide expert opinion as part of dispute proceedings. Failure is not only limited to catastrophic collapses, such as the West Gate Bridge collapse, but also includes defects and non-performance, such as excessive vibration or cracking[2].

In the U.S., forensic structural engineering is recognised as a distinct speciality within the wider field of structural engineering[3]. This recognition came about as a result of a number of significant structural failures in the 1970s and 80s,

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[2] Failure is defined as 'an unacceptable difference between expected and observed performance' (from G. A. Leonard's *Investigation of Failures,* 1982). In this paper, for clarity, the term *failure* is taken to include defects, non-performance, etc. Further discussion of failure terms is presented in Chapter 9 of the *Forensic Engineering Handbook* by Robert Ratay (ed.), where David H. Nicastro provides useful definitions of defects, distress, and failure: '*Defects* are deleterious nonconformities (deviations from referenced standards or specified characteristics) of a component or system. Defects can be thought of as flaws that are introduced through poor design, manufacturing, fabrication, or construction before a structure begins its service life, and (less frequently) by inappropriate operations and maintenance during its service life. A *deviation* from a standard or design requirement may be harmless, but when it has the potential to lead to a failure, the deviation becomes a defect. *Distress* is the collective term for the physical manifestation of poor performance as perceivable problems, such as cracks, spalls, staining, corrosion, or decay. Distress can be thought of as symptoms indicating that the defects are present. *Failure* is the ultimate manifestation of distress, resulting in an unacceptable difference between expected and observed performance.'

[3] The following history of forensic structural engineering in the U.S. is taken from the following publications: Kenneth L. Carper, 'ASCE Technical Council on Forensic Engineering: Enhancing The Influence of Forensic Engineering in the United States' (2007), keynote presentation for the International Forensic Engineering Conference: Investigation and Solving Problems, Mumbai, India, 6-9 December 2007; Kenneth L. Carper, 'Quality and safety: the ultimate legacy of forensic engineering,' keynote presentation: Third International Conference on Forensic Engineering, London, UK, 11-12 November 2005; Kenneth L. Carper, 'Technical Council on Forensic Engineering: Twenty-year Retrospective Review,' Third Forensic Engineering Congress (ASCE) San Diego, CA, 2003; Kenneth L. Carper 'Briefing: ASCE Welcomes *Forensic Engineering*,' Forensic Engineering, Vol 164 Issue FE1, Institution of Civil Engineers', 2011.

which generated intense public scrutiny of the construction industry and the structural design profession. For example, the progressive collapse of a 26-storey reinforced concrete residential tower at Bailey's Crossroads, Virginia, caused the deaths of 14 construction workers in March 1973, and the failure of walkways in the Hyatt Regency Hotel in Kansas City, Missouri resulted in the deaths of 114 occupants in July 1981.

These failures, among many others, led to U.S. Congressional hearings from 1982 to 1984, and culminated in the formation of the Technical Council on Forensic Engineering (TCFE) in 1985[4]. Over the past 30 years the TCFE has focused on improving the quality of forensic engineering investigations, promoting ethical conduct for expert witnesses, and ensuring the effective dissemination of failure information throughout the industry[5]. These efforts were instrumental in achieving recognition of forensic engineering as a distinct speciality, with the *Guidelines for Failure Investigation*[6] stating that 'A new discipline has been created to deal with the investigation of failures and performance problems in the built environment. This discipline requires of the engineer the full spectrum of scientific skills as well as exemplary qualities of character. This new discipline is known as Forensic Engineering.'

While forensic engineering is well known in the U.S., in Australia the wider engineering profession remains largely unaware of the speciality[7]. Given that Australia did not suffer a sustained period of dramatic structural collapses and loss of life, this is not surprising - there has not appeared an overt need for the profession to develop such expertise[8]. In many ways, forensic engineering is

[4] The TCFE was formed by the American Society of Civil Engineers. The choice of the word *forensic* in the Council's title was not without controversy: Neal FitzSimons noted 'that the words "forensic engineering," strictly interpreted, implied activity solely related to litigation, and that use of such a narrow title would suggest a limited scope for the council.' However, Joseph Ward argued that this limitation could be 'dispelled through positive contributions from the Council' (Carper, 2005). Interestingly, upon the formation of the ICE Forensic Engineering Journal in 2011, Carper notes that 'At the initiation of the JPCF [Journal of Performance of Constructed Facilities] 24 years ago, to name a journal *Forensic Engineering* would have been ill-advised. It is indeed a testament to the contributions of the many individuals working within the professional societies mentioned earlier that the title of the new ICE journal now carries positive connotations.'

5 One of the challenges facing the TCFE at the time was to overcome the tarnished image of engineers acting as expert witnesses resulting from the poor ethical standards of a number of practitioners. Carper records that 'Attorneys and the experts who provided technical advice to the courts were viewed with considerable distaste by some design professionals' (Carper, 2007).

[6] American Society of Civil Engineers (1989), *Guidelines for Forensic Investigation*, developed by the TCFE.

[7] One of the few forensic structural engineering publications from an Australian perspective is that by D. Campbell-Allen titled *Forensic Engineering – A Need In Australia?* published by The Institution of Engineers, Australia in 1987. The paper 'sets out to examine the ways in which failures are reported and studied and to suggest ways in which "forensic engineering" should be developed in Australia as part of the world of engineering construction.' The paper concluded that there was a need for the dissemination of failure information and to identify the procedural causes of failure.

[8] While the collapse of the West Gate Bridge in 1970 tragically resulted in the loss of 35 lives, failures of this magnitude have been few, with damage from disasters such as the Granville rail crash, Cyclone Tracy, and the Black Saturday bush fires being considerably more devastating.

in a similar position to that of forensic accounting almost 20 years ago, when the value of forensic accounting was not well known - a situation which has changed in the intervening years as the benefits of forensics have become more apparent to both the accounting and legal professions[9].

The engineer as expert witness: design and forensics

For legal teams engaging structural engineers as expert witnesses, the practical consequences of this lack of forensic expertise in Australia are all too familiar: investigators can concentrate on finding solutions to rectify failures rather than identifying causation; investigators can base their expert opinion on assumptions rather than verifiable evidence; and, ultimately, the cause of failure may neither be identified nor communicated in a forensically sound manner.

In order to understand the reasons why investigations fail in this manner, it is necessary to understand the nature of the role typically played by the expert in their day-to-day engineering activities and how it is ill-suited to failure investigation. The benefits of forensic expertise can then be examined and practical guidance can be provided to assist legal teams to ensure expert witnesses perform causation investigations in an independent, transparent, and clear manner.

The engineer as designer

Fundamentally, engineers design[10]. In *To Engineer is Human*, Henry Petroski defines structural engineering as 'the science and art of designing and making, with economy and elegance, buildings, bridges, frameworks, and other similar structures so that they can safely resist the forces to which they may be subjected' [11]. While this definition describes the objective of structural engineering, another, quite facetious description provides some insight into the *process* of structural engineering: '*Structural Engineering* is the art and science of molding Materials we do not fully understand; into Shapes we cannot precisely analyze; to resist Forces we cannot accurately predict; all in

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[9] Paul Vincent (Vincents Chartered Accountants) and David Van Homrigh (KPMG), personal communications (2011).

[10] The design process is not only limited to practising designers, 'but runs through the profession as a whole. (While many engineers involved in construction and maintenance may not engage in design on a regular basis, they typically approach problems using a design process.) Indeed, the engineer as designer is so fundamental to the engineering profession that engineers rarely think of themselves as designers, rather, as *engineers* with specific design experience and technical competency. In essence, the design mindset underpins what it is to be an engineer, it is the basis of university training, and it cements the role of engineers as *problem solvers.'* from S.P. Brady (2011),'The Role of the Forensic Process in Investigating Structural Failure.' ASCE *Journal of Performance of Constructed Facilities*, accepted 2011. Also see D. Charrett (2010) 'The Engineer is Dead. Long Live the Engineer!' for a discussion of the many roles and responsibilities, in addition to a technical role as a designer, undertaken by the modern structural engineer.

[11] H. Petroski (1992) *To Engineer is Human*.

such a way that the society at large is given no reason to suspect the extent of our ignorance[12]'.

The inclusion of the latter definition is not intended to treat the structural design process in a glib or disrespectful manner, but it does present a fascinating insight into the challenges faced by an engineer in order to produce a workable design. Design is a process of synthesis, which does indeed rely on simplifying performance assumptions relating to probable loads, structural behaviour and material properties – assumptions which are conservative and have been codified over the years to produce efficient and generally safe structures. To design structures by attempting to precisely predict the loads they will carry, how they will behave, and their material properties would be hopelessly inefficient and time-consuming. Ultimately, the conventional design process is efficient, well respected, and relies on industry accepted simplified performance assumptions and the designer's experience.

When it comes to providing expert witness services, the design process plays a number of important roles. For example, the terms of the settlement of a dispute may be dependent on the details of a design engineer's design to rectify the failure. Further, when causation has been determined, expert testimony may be required to ascertain whether an engineer designed the structure with the degree of reasonable skill and care expected of a practising engineer, a role for which engineers who typically utilise the design process are excellently placed because of their knowledge of standards and professional engineering practice.

Based on these attributes, an engineer who utilises the design process may appear to be the ideal candidate to determine causation of structural failures. However, this is typically not the case, with the phenomenon being well documented internationally. Kenneth Carper, in his text *Forensic Engineering* (2000), stresses the importance of forensic rather than design expertise in determining causation, concluding that 'a good design professional is not necessarily a good forensic expert.' Overall, the engineer utilising design expertise alone will encounter significant difficulties establishing causation, despite the fact that they may have design experience relevant to the structure under consideration[13].

An examination of a number of the key aspects of the design process illustrates why these difficulties exist.

- First, the objective of the design process is to identify and develop engineering solutions, not to determine causation. It is, therefore, not surprising that experts without forensic expertise gravitate towards providing solutions to rectify the failure, or rely on determining the

[12] James Amrhein, 1988, quoted by Kenneth Carper (2000) in *Forensic Engineering*, Second Edition.

[13] G. Bell, in Chapter 8 of K. Carper's text *Forensic Engineering* (2000) also notes that 'Few successful designers are good failure investigators; the reverse is also true. The handful of exceptions are talented individuals who have extraordinary insight into engineering principles; they can apply that insight to either function.'

cause of failure in the form of 'I wouldn't have designed the structure in this manner, so this must be related to the cause of failure'[14];

- Second, although the engineer may have significant design experience, a successful investigation requires expertise generally not encountered in the design process. For example, while the design process typically relies on simplifying performance assumptions, in failure analysis the investigator must determine actual loads, actual structural behaviour, and actual material properties at the time of failure based on physical evidence – a process which requires an experienced investigator[15];

- Finally, successful investigations require that a range of failure hypotheses be considered for the failure in question, some of which may not be routinely encountered in design.

These limitations affect how a design engineer approaches causation investigations. While determining causation may be critical to the legal team's case, such an expert may be utilising a process that naturally moves the focus of the investigation away from this objective – commonly leading to frustration in both parties. If the expert fails to adequately collect and interpret physical evidence and instead relies on assumption, there is a risk these assumptions may be called into question in the face of evidence. Likewise, difficulties can arise if the expert fails to consider a particular failure hypothesis which later becomes relevant. Obviously, these issues have significant consequences for the legal team.

The engineer as investigator

The key to determining structural causation is knowledge of, and experience in, the application of the forensic process. The forensic process aims to objectively identify the technical cause or causes of failure using available evidence. Randall Noon, in his text *Forensic Engineering Investigation* (2000), states that 'a forensic engineer relies mostly upon the actual physical evidence found at the scene, verifiable facts related to the matter, and well-proven scientific principles. The forensic engineer then applies accepted scientific methodologies and principles to interpret the physical evidence and facts.'

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[14] 'This method of identifying the cause of failure appears to be based on the premise that because the engineer has utilized a certain design approach that has been successful in the past, and the approach utilized in the failed structure is different, then this is the *obvious* cause. While such an approach may provide a *clue* to the cause of failure, it is not forensically sound.' from S.P. Brady (2011), 'The Role of the Forensic Process in Investigating Structural Failure.' *ASCE Journal of Performance of Constructed Facilities*, accepted 2011.

[15] 'At this point, a number of engineers may protest that they have successfully investigated failures in the past without the use of the forensic process. In some situations, particularly where causation is straightforward and obvious, engineers do appear to identify causation successfully. But the process utilized typically involves the engineer assuming the cause of failure and preparing a design solution to address it - essentially demonstrating causation because the solution resolved the issue. This is a trial and error approach to remediation, rather than a forensically sound attempt to establish causation.' from S.P. Brady (2011), 'The Role of the Forensic Process in Investigating Structural Failure.' *ASCE Journal of Performance of Constructed Facilities*, accepted 2011.

The forensic process of collecting evidence, developing failure hypotheses, testing each hypothesis against the collected evidence, and determining the most likely cause of failure, is a process of analysis, rather than synthesis. The application of the forensic process is best described by Noon: 'First, careful and detailed observations are made. Then, based upon the observations, a working hypothesis is formulated to explain the observations. Experiments or additional observations are then made to test the predictive ability of the working hypothesis.' Noon then goes on to say that, 'As more observations are collected and studied, it may be necessary to modify, amplify, or even discard the original hypothesis in favor of a new one that can account for all the observations and data. Unless the data or observations are proven to be inaccurate, a hypothesis is not considered valid unless it accounts for all the relevant observations and data'[16].

This process avoids many of the pitfalls of applying a design process alone. The objective of the process is to identify the cause of failure, and the process is driven by ruling in or ruling out a failure hypothesis based on specific evidence and generally accepted engineering principles, rather than simplifying assumptions. In other words, the forensic process relies on understanding how the structure actually behaved, rather than predicting how the structure would have behaved based on the design process. The separation of evidence collection from development of hypotheses, in conjunction with the rigorous testing of each hypothesis against the evidence, is a key aspect which assists the investigator to conduct the entire investigation in a forensically sound manner, ensuring it will not only stand up to the scrutiny of engineering peers, but also to the rigorous demands of the legal system.

Given the significant differences between the forensic and design processes, it starts to become clear why Carper can make the point that 'a good design professional is not necessarily a good forensic expert.' The determination of causation will be very difficult unless the design expert is able to put aside their traditional design process and apply a forensic process. In practice, however, such a transition may be highly problematic, with a number of legal professionals likening it to the transition difficulties experienced in moving from front end law to back end law, and vice versa.

Fundamentally, it is experience in the application of the forensic process that is critical, and this cannot be attained through design experience alone. Without experience in forensics, the embedded nature of the design process in an engineer's psyche – sometimes subconsciously – makes it very difficult for engineers who design on a regular basis to actually embrace the new set of attitudes, approaches, and processes necessary to investigate causation satisfactorily.

[16] In testing the various failure hypotheses, Noon, in *Scientific Method: Applications in Failure Investigation and Forensic Science* (2009), provides a helpful summary of the attributes of a good working hypothesis: 'All the data upon which it is based needs to be factually verifiable. It must be consistent with all the relevant verifiable data, not just selected data. The scientific principles upon which the hypothesis relies must be verifiable and repeatable. The hypothesis should provide some predictive value. The hypothesis must be subjected to and withstand genuine falsification efforts.'

Managing the forensic process

For the legal team managing the engineering expert, there are a number of warning signs that suggest an expert may be moving away from a forensically sound method of investigating causation. These include:

- Rectification development: The expert's focus has moved to development of rectification options, suggesting causation may no longer be a primary focus;

- Short site visit: The initial stages of the investigation involve only a cursory visit to the site of the failure, suggesting that the identification and collection of physical evidence may not be a focus for the expert;

- Theoretical analyses focus: The expert becomes more concerned with undertaking theoretical analyses rather than careful analysis of the available physical evidence, which suggests that the investigation may be becoming a more traditional design driven process rather than an evidence driven process;

- Inadequate evidence: The expert deems causation to be proven without supporting evidence, based on the premise that 'I wouldn't have designed the structure in this manner, so this must be related to the cause of failure';

- 'Cherry picking' evidence: Evidence which appears to contradict the expert's most likely hypothesis of failure is dismissed as being irrelevant without adequate explanation, which can suggest that the expert may be focusing on one hypothesis, despite potentially contradictory evidence;

- Lack of open mind: The expert reaches a strong conclusion on causation early in the investigation, which may indicate that the expert has a preconceived opinion as to the cause of the failure and is focusing on one hypothesis to the exclusion of others;

- Reporting: Reports do not exhibit a reasonable separation of assumption from evidence, making it difficult for the legal team to determine whether the expert's opinions are based on verifiable evidence or assumptions that may be open to challenge.

On the other hand, there are a number of steps that the legal team can take to ensure the forensic integrity of investigations:

- Relevant expertise and experience: Though it may sound obvious, it is essential the legal team ensures that the expert has the appropriate level of forensic expertise and experience, not just expertise and experience in design. A review of the expert's resume for experience in identifying causation rather than solution development can give some indication of the level of forensics;

- Early forensic involvement: Physical evidence in structural disputes can be of a perishable nature – for example, fracture surfaces corrode and debris can be removed. Therefore, it is advisable to involve an engineer with forensic expertise at an early stage to preserve, record, and collect all physical evidence related to the failure;

- All evidence is important: Ensure all evidence is accounted for and included in the expert's consideration. Question the basis for any evidence being ruled out as irrelevant;

- Numerous failure hypotheses: Ensure a wide range of failure hypotheses is considered by the expert;

- Nature of the basis of opinions: It is typical for the legal team to probe the basis for the expert's opinions. However, it is also important to ensure the expert has a clear understanding of the *nature* of the information they rely upon to formulate their opinion: Is it evidence which can be verified? Is it an assumption which may be challenged as being incorrect for the structure in question? Or is it generally accepted engineering principles which are unlikely to be challenged? This will assist the legal team to assess the strength of the opinion, and can assist the expert unearth implicit assumptions. Equally, the legal team should ensure the expert has a clear understanding of the information they rely upon to deem all other failure hypotheses less probable. Finally, ensure the expert expressly notes any specific assumptions that the legal team has asked the expert to make in forming opinions[17];

- Reporting: Ensure there is a clear separation of evidence, assumption, and scientific principles in the report. *The Guidelines for Forensic Engineering Practice*, published by the American Society of Civil Engineers in 2003, provides an excellent guide for the disciplined management of this separation.

Further resources

Several U.S. publications are available on the topic of forensic structural engineering[18], but the following specific publications are likely to be of interest to Australian legal professionals involved in construction disputes.

The *Guidelines for Forensic Engineering Practice*[19] is an excellent introduction to forensic investigation. The guidelines cover forensic

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[17] With respect to expert witnesses having differing opinions, Noon, in *Forensic Engineering Investigation* (2000), provides the following comment: 'Honest disagreements between two qualified experts can and do occur. When such disagreements occur, the focus of the criticism should be the theoretical or factual basis for the differences.'

[18] For example: *Forensic Engineering* (Carper, 2000), the *Forensic Structural Engineering Handbook* (Ratay, 2010), and *Beyond Failure: Forensic Case Studies for Civil Engineers* (Delatte, 2008), *ASCE Journal of Performance of Constructed Facilities* (edited by Kenneth Carper).

investigation techniques, but also include chapters on ethics and working within the U.S. legal process.

From an Australian perspective, a special issue of the *Australian Journal of Structural Engineering* was published in 2010, which focused on forensic engineering. Included is a paper by legal professionals titled *Australian Legal Guidelines for Forensic Engineering Experts*, which provides guidance to engineers considering putting themselves forward as expert witnesses in engineering disputes[20]. A companion paper by Shnookal and Shaw, covers the ethical considerations for the engineer acting as expert witness - both authors are barristers, with a history as practising engineers[21].

Closure

While design expertise plays a key role in producing new structures and contributes to resolving legal disputes, forensic expertise plays a critical role in improving expert witness services in construction disputes involving causation. Given the wider structural engineering profession's lack of awareness of forensic expertise, combined with the significant differences between the forensic process and the more commonly applied design process, it is not surprising that many structural experts experience difficulties in determining causation in a forensically sound manner.

All too often, these issues lead to frustration in all parties, skewed dispute outcomes, and damage to the reputations of both the legal team and the expert witness. For legal teams, ensuring the expert has the necessary ability to actually determine causation should be a critical consideration; an ability generally governed by their forensic expertise and experience.

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[19] Lewis, Gary L. ed., 2003, *Guidelines for Forensic Engineering Practice*, American Society of Civil Engineers.

[20] Murphy, P.J., Duthie, L., Bielert, B., and Charrett, D. 'Australian Legal Guidelines for Forensic Engineering Experts', *Australian Journal of Structural Engineering*, Vol 11 No 1, 2010.

[21] Shnookal, B. A. & Shaw, J.M., 'The ethics of forensic engineers,' *Australian Journal of Structural Engineering*, Vol 11 No 1, 2010.