Failure investigations and the

In the first part of a two-part article, Sean Brady explores the differences between a good designer and a good forensic engineer.

Interest in forensic engineering within our profession has increased in recent years, with many engineers becoming curious about how to become a forensic engineer, the expertise required, and what lessons can be learned from previous failures.

The subject is discussed in a number of recent publications, including Robert Ratay's *Forensic Structural Engineering Handbook*[1], which comprehensively introduces the speciality of forensics, and Norbert Delatte's *Beyond Failure*[2], which provides a detailed and accessible collection of the lessons learned from a number of key failures, such as the I-35W bridge collapse and the 9/11 terrorist attacks.

Such interest is to be welcomed because it not only generates discussion of the lessons from failure, but it also provides an opportunity to highlight the importance of further developing investigative skills within the wider structural engineering profession. This is not to suggest we should all become 'forensic engineers', certainly not - structural engineering will (and always should) have a far greater need for design engineers - but it is important to explore the differences between the expertise required to conduct a failure investigation as opposed to designing and constructing a new structure.

It is in this regard, that Ken Carper's classic *Forensic Engineering*[3] highlights one of the key differences between forensics and design by concluding that 'detective' skills, as opposed to 'design' skills, are a key requirement for an investigator. Carper goes on to say that 'a good design professional is not necessarily a good forensic expert,' which appears a contradictory statement: after all, surely an engineer that regularly designs a certain type of structure is the ideal candidate to investigate why such a structure failed?

However, this apparent paradox does exist, and this article explores why forensics and design are so different, with Part 1 concentrating on the different processes that underpin the two specialities. Part 2 will explore the practical consequences that result from the correct and incorrect implementation of these processes in practice.

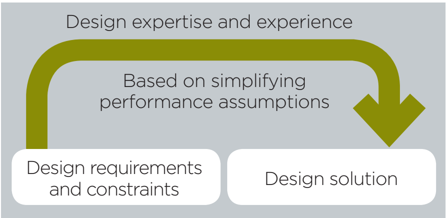
Design

At a most fundamental level, engineers design[2]. While not all engineers are designers - many are involved in construction and management - our university and professional training instils and develops a problem solving process that is primarily design based. Essentially, we are trained as problem solvers, who utilise a design process to resolve issues.

The design process tends to focus on developing a design solution, from a suite of potentially viable alternatives, that meets a client's requirements while respecting their constraints. Design is, therefore, a process of synthesis, where the designer treads a (typically) conflicted path between client requirements and constraints (Figure 1). Designer's navigate this path using their design expertise and experience, with the appropriateness of a particular design solution being evaluated using simplifying performance assumptions relating to how such a design will behave once constructed.

The use of the word 'simplifying' should not be construed in the negative, quite the contrary: the (relative) ease of implementation of these assumptions permits calculations to be undertaken in an efficient manner to meet the commercial realities of being a structural engineer. Many of these assumptions are codified or well known rules of thumb, they are generally conservative, and their appropriateness has been confirmed over time by trial and error to produce generally safe structures. Further, the profession accepts that these assumptions are indeed a simplified representation of reality, with their role being to manage (rather than investigate) design unknowns; a prudent course given the inevitable adaptation a design is forced to endure during its transition from concept to constructed reality.

Figure 1
Design process



Failure investigation

Clearly, the design process plays a central role in engineering design, but it also plays a role when structural failure occurs. For example, it may be required to rectify or replace the failed structure. It is also pertinent in legal disputes when there is a requirement to ascertain whether or not the original design was prepared with the reasonable skill and care required of a practising engineer.

However, issues arise when the design process is utilised to determine the cause of structural failure (or causation), and it is here that the gap between design and forensics becomes apparent. This is not to suggest that engineers approach the investigation of failure by attempting to design a solution rather than identify cause, but experience suggests that in the absence of an alternative process, many engineers fall back, generally unaware of the transition, on their existing design process and apply it by default.

Two specific issues can arise when this occurs: the investigation develops a focus on rectification, instead of retaining a focus on causation; and the investigation develops an overreliance on simplifying performance assumptions instead of physical evidence[4].

Given the objective of the design process, it is not surprising that a causation investigation gives way to a focus on rectification. In practice, many engineers appear to terminate the causation investigation not when they have established causation in a forensically sound manner, but when they believe they have sufficiently understood the issues at hand in order to explore solution development; a clear case of managing unknowns, as opposed to investigating them.

In purely technical terms, such an approach may fail to identify the actual cause of a failure in situations of complex causation, and, in legal disputes, there can be serious ramifications because the clear establishment of causation is critical to establishing legal liability. This issue leads to the all too common standoff between lawyers and engineering experts: lawyers become frustrated because engineers appear only interested in fixing a failure, while engineers become frustrated because

forensic process (part 1)

lawyers only appear interested in assigning blame for a failure.

The second issue is an overreliance on simplifying performance assumptions instead of physical evidence. This is to be expected given that design is an assumption-driven process. In a failure investigation, however, each and every assumption should be confirmed, if possible, by evidence specific to the failure. Given the sometimes significant differences between the simplifying assumptions adopted in design and how structures actually behave in practice, the investigator should attempt to determine the actual loads on a structure, its actual structural behaviour, and the actual material properties at the time of failure in order to assess whether or not failure would have occurred. As stated previously, this issue is particularly important in legal disputes because of its focus on evidence, and an investigation that over relies on assumptions may be viewed as being forensically unsound.

Forensics

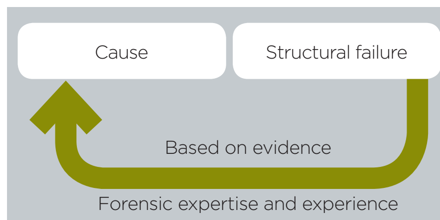
The key to the determination of causation in a forensically sound manner is the use of the forensic process (Figure 2). The forensic process is essentially the implementation of the Scientific Method, with the process focusing on evidence collection, failure hypotheses development and failure hypotheses testing.

While the design process is one of synthesis, the forensic process is one of analysis. While the objective of the design process is solution development, the objective of the forensic process is to establish causation utilising verifiable evidence, as opposed to assumptions. The process is ideally suited to failure investigation, particularly in the context of a legal dispute.

The forensic process generally begins with an investigator collecting and collating physical evidence relating to the failure in an objective manner. Objectivity is critical. The significance of specific pieces of evidence may not be apparent at the outset of an investigation, and loss of objectivity often results in the investigation converging at too early a stage, with critical pieces of evidence going unrecorded.

During the failure hypotheses development stage, the investigator develops a broad range of theories as to what may have caused

Figure 2
Forensic process



the failure. In practice, an investigator will oscillate between the evidence collection and hypotheses development stages: further evidence will suggest further hypotheses, which in turn will prompt a further search for evidence. Over-convergence of the investigation at this stage can result in viable hypotheses going unidentified.

Finally, the hypotheses testing stage involves the evaluation of the likelihood that a particular hypothesis caused the failure. A typical approach with structural failures is to evaluate theoretically how a structure would behave when subject to the conditions and loading, as confirmed by evidence, at the time of failure. If such analysis suggests that failure would occur then the manner in which the analysis predicts collapse can be compared directly to the evidence retrieved from the failure site to establish the analysis' validity. At each point in such testing, evidence takes precedence over assumption, and hypotheses can (hopefully) be ruled in or ruled out to determine the single failure hypothesis that explains the failure.

As is obvious, the successful identification of causation is primarily dependant on the quality of evidence available to test the failure hypotheses. Comprehensive evidence allows hypotheses to be confidently ruled in or out, while sparse evidence often results in an investigation being inconclusive because it is not possible to narrow the field of hypotheses.

Forensics and design

The forensic and design processes are clearly quite different and a key consideration for an engineer with conventional engineering (design) expertise and experience wishing to investigate failures is to ensure they put aside their design process and utilise a forensic process. This transition, however, will not be without significant difficulties, and the literature suggests that few engineers appear to be proficient in both[1,3,4].

For example, a good designer uses familiar simplifying performance assumptions to develop design solutions; assumptions that they have personally relied upon throughout their career to design successful structures. A designer's confidence in such assumptions is paramount to avoid second guessing and bringing the design process to a halt. However, asking such an engineer to investigate a failure is essentially asking them to doubt, to scrutinise, and to challenge the very assumptions they rely upon on a day to day basis in design. Conversely, asking a forensic engineer to undertake design requires them to place unsubstantiated trust in the very assumptions they systematically doubt, scrutinise, and challenge on a day to day basis.

Closure

The importance of these forensic or 'detective' skills in failure investigations cannot be overstressed. This form of expertise is quite different to that utilised by the majority of professional engineers, with the literature suggesting that design expertise often acts as an impediment to effective investigations.

In part 2, we will explore how, in practice, the design process impedes effective investigations, and examine the steps engineers can take to ensure their investigations determine the causes of engineering failures in a forensically sound manner.

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