Failure investigations and the

Here, Sean Brady assesses the strengths and weaknesses of applying engineering analysis to the forensic process.

In the first part of this article, published last month[1], we examined the differences between the forensic and design processes and explored, from a largely philosophical perspective, the negative consequences that can ensue when the design process is applied, typically inadvertently, to the investigation of structural failure.

The objective of the design process is to provide a solution that meets a client's requirements, while respecting their constraints. It is a process of synthesis that relies on both an engineer's design expertise and experience and the use of simplifying performance assumptions relating to how a constructed structure will behave in practice.

By contrast, the objective of the forensic process is to identify the cause of engineering failure in a forensically sound manner. It is a process of analysis, as opposed to synthesis, and it relies on an engineer's forensic expertise and experience, which is quite different to design expertise and experience. Also, instead of relying on simplifying performance assumptions, it utilises evidence to estimate the actual loads on a structure at the time of failure, the actual behaviour of a structure, and the actual capacity of a structure to resist these loads.

The forensic process is therefore characterised by evidence collection, the development of a wide range of failure hypotheses, and the testing of these hypotheses against the collected evidence to determine the cause of failure. While this process is required for the investigation of failures, engineers are typically unfamiliar with its elements, and many drift back to applying the design process, with an investigation typically developing a rectification focus and an overreliance on simplifying performance assumptions.

Here, we will examine two practical issues that can manifest relating to evidence collection and engineering analysis, and we will discuss how an engineer with a predominantly design background can avoid these pitfalls and develop their forensic capability. (A more comprehensive discussion of these issues, and others, can be found in the literature[2-6]).

Evidence collection

A serious issue that often develops is, for all intents and purposes, the bypassing of the evidence collection phase, with the investigator proceeding to the hypotheses development phase. This is unsurprising; the design process has no provision for evidence collection, as it is typically concerned with developing a workable design solution and evaluating that solution's potential behaviour and future performance.

The most significant consequences of this lack of focus on evidence collection usually occur during the inspection of the failure site. Rather than undertaking a slow, independent, and transparent collection of physical evidence, many investigators instead try to determine 'what caused the failure' - in effect commencing the hypotheses development phase.

Not only is this a distraction from evidence collection, but once hypotheses development commences, there is a tendency to view the physical evidence through the prism of these failure theories.

In essence, this is allowing theory to drive evidence, as opposed to evidence driving theory, with investigators sometimes becoming susceptible to 'confirmation bias', where they only tend to notice evidence that supports their failure theories. In practice, this tends to manifest itself as the investigator quickly forming a view of what caused the failure (in many cases based on a review of the drawings and a brief review of the failure site), then taking a number of cursory photographs to support this view, and finally leaving the site with a feeling they have understood what caused the failure.

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However, such an approach, although all too common, often results in a forensically unsound investigation because key evidence – where its significance is not appreciated or it does not fit with the preconceived failure hypotheses - goes unrecorded. This is a particular concern for structural engineering investigations because of the perishable nature of structural evidence (e.g. failure surfaces corrode, structural steelwork is sent for recycling) and the client's urge to 'clean up' after a collapse. Once the opportunity to record such evidence is lost, it usually cannot be reproduced at a later point in the investigation when it may be required to rule in or rule out specific failure hypotheses or to further examine some unexplained aspect of failure.

The solution is to suspend hypotheses development until evidence collection is reasonably well advanced, and to undertake the slow, meticulous and transparent documentation of all evidence. (It is worth acknowledging that such an approach is very often at odds with the physical realities of a failure site: clients want answers quickly and their urge to 'clean up' and move on from the failure can be all consuming).

In other words, when arriving on the failure site, the investigator should not think in terms of 'what caused this failure', but rather 'what do I see', then record it. When the hypotheses development stage does commence (typically before evidence collection is complete) it is critical to keep all hypotheses on the table for as long as possible and to avoid becoming fixated on a specific failure theory. In practice, once disciplined separation of the evidence collection and hypotheses development phases is maintained, the two phases tend to inform and support each other, i.e. certain failure hypotheses will prompt a search for specific evidence to prove or disprove this theory, which in turn may suggest previously unconsidered failure hypotheses. One helpful approach with the overall collection of evidence is to ask oneself what photographs and samples would be required at a later date to 'prove' what was observed on site, then to take these photographs

forensic process (part 2)

and samples. In this regard, for example, photographs of un-failed components are just as important as failed components, and photographic evidence of the order in which components were recovered can provide a valuable indicator as to the order in which specific components failed.

Ultimately, it is worth bearing in mind that the ability to rule in and rule out specific failure hypotheses at a later stage of the investigation will be largely dependent on the quality of the evidence collected at this inspection stage. Good, independent evidence collection will assist in narrowing the field of likely failure hypotheses, while poor evidence collection will result in numerous failure theories staying in play because the evidence required to separate them is simply unavailable.

Engineering analysis

Quite a different problem exists when it comes to engineering analysis. Unlike evidence collection, engineering analysis, particularly finite element analysis, is all too familiar to an engineer that typically utilises a design process. This is not to suggest that finite element analysis has no place in a forensic investigation, far from it, such analysis typically plays a very important role during the hypotheses testing phase in determining if, and how, certain loading conditions could result in the failure of the structure. However, engineering analysis is often one of the most misused tools in failure investigation, with the primary issue being an over-emphasis and over-reliance on such analysis.

Fundamentally, engineering analysis often appears as an ideal starting place when attempting to understand why a structure failed. It provides insight into the important aspects of a structure's behaviour and how the original designer envisaged the structure would work. It also provides 'clues' as to where deficiencies may exist. However, there are problems and limitations with this approach.

Firstly, a focus on analysis at a very early stage in the investigation can prove a major distraction from the main task of evidence collection. The time for a focus on analysis is after, not before, evidence collection.

Secondly, engineering analysis is based on assumptions with respect to loading, material properties and how the structure is expected to behave in practice. In design, many of these assumptions have been codified and well understood, and they have been shown to produce efficient and generally safe structures. However, in a failure investigation, the appropriateness of each of these assumptions needs to be investigated and confirmed (where possible) with evidence specific to the failed structure. Therefore, the validity and helpfulness of such engineering analysis is largely dependent on the validity of the assumptions it's based upon. However, these assumptions do not always receive the attention they deserve, and in some cases the findings of such analysis can be regarded as questionable due to a lack of evidence, or even found to be invalid due to evidence coming to light later in the investigation, that shows the assumptions were inappropriate.

The third issue relates to how such engineering analysis is actually used in the investigation. Used correctly, it plays a key role in the hypotheses testing phase to assess, according to engineering principles, whether certain scenarios would result in failure. For example, a finite element model of a structure could be subjected to the wind loading, based on meteorological records at the time of the failure, to assess the likelihood of such failure. If the analysis indicates failure was unlikely, than this information can assist in ruling out wind loading as a potential cause. However, engineering analysis is often not used in this manner. Commonly it is used to assess whether the structure, as designed, complied with the relevant design standards, with a lack of compliance being deemed as the cause of failure. This approach is essentially the direct application of engineering analysis from the design process, and it is forensically unsound because it does not consider the actual conditions present at the time of the failure. Unfortunately, it occurs all too frequently in failure investigations, with many investigators insisting on its validity. History, however, teaches us that many structures that complied with the relevant standards collapsed in practice, and many structures that were deficient in the eyes of the standards continued to operate satisfactorily.

Ultimately, the investigator should utilise the strengths of engineering analysis, while also understanding its limitations – particularly in the case of finite element analysis where model complexity can 'bamboozle' investigators with the illusion of accuracy. Engineering analysis is strong in determining how structures potentially behave when subject to certain loading and material conditions, but it is weak in assessing the validity of such loading and material property assumptions. Such an assessment should primarily be undertaken using physical evidence and a transparent forensic process.

Closure

The forensic and design processes are very different. For an engineer wishing to develop a forensic capability, with a background in design, a key step is to acknowledge these differences. The building of forensic capability can then commence, with the engineer focusing on developing an understanding of how structures fail in practice, as opposed to how they are designed, understanding the technical tools available for forensic analysis, and keeping in mind that perhaps the greatest gap in their current expertise is an understanding of the importance of evidence, and the critical role it plays in sound forensic investigation.

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