



Determining Negligence in Engineering Failures

An Online Continuing Education Course for Engineers

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Determining Negligence in Engineering Failures

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1. Introduction

In creating products for clients or the general public, engineers have an ethical duty to strive to prevent the products from harming anyone. Thus when a product fails and someone is injured or killed, the question always arises whether the engineers responsible for the product were guilty of negligence.

Negligence may be defined as the failure to exercise the standard of care that a prudent engineer would exercise under the same circumstances. Thus to determine if negligence was the cause of a failure, the expected standard of care existing before the failure must first be determined. This can be difficult. The purpose of this course is to describe factors that influence the determination of the expected standard of care. Factors considered are the maturity of the technology, the public's belief that absolute safety can be attained, the magnitude of the risks and their obviousness, prior knowledge of failure modes, biases that might be present in any investigations of the failure, and the public's desire to identify and blame wrong-doers. Based on these considerations, a list of possible causes of engineering failure can be constructed. Negligence is one of these causes, and the only one that involves a moral failing of the engineers involved with the failure.

These concepts are illustrated with a description of four case studies illustrating failure causes ranging from gross negligence to absolutely unforeseeable events.

2. Expected Behavior of Engineers and the Safety, Health and Welfare of the Public

In terms of the well-being and protection of the public, expectations for engineers are defined through laws, regulations and codes of ethics. Laws express these expectations through the concept of "negligence."

2.1 Negligence

State licensing boards, laws, and professional organizations typically offer a definition of negligence similar to the following: [1, 2, 3]

Negligence in the practice of professional engineering means the failure to behave with the standard of care that a professional engineer of ordinary prudence would have exercised under the same circumstances. The behavior usually consists of actions, but can also consist of omissions when there is some duty to act.

In a trial, deciding what is the expected standard of care and whether or not it has been met is usually beyond the expertise of lay people without the assistance of expert witnesses, although some acts of negligence are so obvious that even non-engineers can judge. An example of obvious negligence would be a structural engineer who was hired to review structural plans but approved them without having even seen them. It should be stressed, though, that even when expert testimony is given at a trial, the question of whether negligence has occurred still is decided by the jury. Even though jury members may lack expertise in a technical subject, they still must make a judgment about whether an expert witness is credible, or, when experts disagree, about which expert to believe.

2.2 More on standard of care

An important factor in defining the standard of care required in a particular technological application is whether the technology involved is mature or immature. “Mature” technologies have well-established design rules codified in design manuals and even in legal codes. Many instances of the technology have been implemented and designers have a large body of experience—their own or other’s—to draw upon. Because of this extensive experience with the technology, almost all possible failure modes have been identified, and techniques for avoiding them are known. Reinforced concrete used in bridge design is an example of a mature technology.

In contrast, immature technologies do not have well-established design rules; in fact, design rules may be developed as part of a project using the technology. Because designers have comparatively little experience to draw upon, much analysis and small-scale testing of components are required, and the probability is greater that not all failure modes have been identified. Many subjective judgments must be made about whether or not experiments and calculations have been sufficient. The project consists as much in determining the design rules as in actually following the rules to produce a final product. The Apollo project to place a man on the moon involved much immature technology.

The point in drawing this contrast between mature and immature technologies is that the “standard of care” and “ordinary prudence” expected are quite different for the different technologies—what indeed does “ordinary” mean when a new technology is applied for the first time? Any analysis of engineering failure must take this difference in maturity into account when judging if standard of care and ordinary prudence considerations have been met.

2.3 Codes of ethics

In addition to laws against negligence contained in governmental statutes, statements defining expected standards of ethical behavior are written in the codes of ethics of many engineering professional organizations. Typical statements are “Engineers shall hold paramount the safety,

health and welfare of the public ... and “Engineers shall recognize that the lives, safety, health and welfare of the general public are dependent upon engineering judgments, decisions, and practices incorporated into structures, machines, products, processes and devices.” [4] These statements of what constitutes ethical behavior amount to saying “Don’t be negligent.” That is, according to the definition of negligence stated above, an engineer should exercise a standard of care that a professional engineer of ordinary prudence would exercise. Thus codes of ethics and the definition of negligence are equivalent, at least as far as safety of the public is concerned. Codes of ethics cover other topics in addition to public safety, however, such as duty to clients, fraud, and bribery.

3. Safety, Risk, and Uncertainty

When an accident happens and people are injured or killed, questions of safety and risk always arise. To answer these questions, it is important to be clear about what the terms, “safety” and “risk,” mean.

3.1 Safety

The general public tends to believe that safety is a binary property: something is either safe or unsafe, and there is no state or condition in between. For example, expressions such as “life is infinitely valuable,” “the risk of injury or death must be zero,” and “failure is not a possibility” are commonly heard and are all based on the assumption that the probability of failure can be reduced to zero—that is, a “safe” condition can be achieved in the absolute, or binary sense. Many of these ideas are easily refuted. For instance, if life is infinitely valuable, no rational person would ever drive an automobile, since risking something infinitely valuable in a situation where fatal accidents occur would be irrational.

A more realistic definition of “safe” is needed. William Lowrance, in his book, *Of Acceptable Risk*, suggests [5, p.8]

A thing is safe, if its risks are judged to be acceptable.

Lowrance then defines risk as “the probability and severity of harm to human health.” Thus the risk associated with an event can be visualized as a point on a line measuring probability values from zero to one, and something is called safe or unsafe, depending on someone’s subjective judgment of where “acceptable” lies on the line. Risk can be estimated by specialists knowledgeable in the relevant technical area, for example, automotive engineers specializing in crashworthiness. Safety, on the other hand, is determined by a subjective judgment about how much risk someone is willing to accept.

3.2 Uncertainty

Safety and risk have been defined in terms of the probability of failure and thus are based implicitly on frequency distributions. The idea of risk and safety calculated from frequency distributions can be useful in incorporating risk analysis into engineering design. In fact, such probabilistic design approaches are widely used in a number of industries, for example, aerospace, electronics, medical devices, nuclear power, and structural design, to name only a few. In terms of the definition of negligence in law, designers using these approaches would generally be thought to be using the “standard of care” expected of a “prudent person.”

But probabilistic design is not quite the end of the story. In a book published in 1921, the economist Frank Knight made a distinction between “risk,” which applied to situations where the outcome cannot be predicted but the odds can be calculated, and “uncertainty,” where we do not have enough information even to calculate the odds, or worse, we do not even anticipate the manner in which failure could occur. [6]

Knight applied his ideas to investment decision-making in business, and they have been subjected to some criticism over the years. However, in the 2008 U. S. financial crisis, Knightian uncertainty provided a good model of what occurred. Hard-working and highly intelligent financial analysts, many with doctoral degrees in mathematics and physics, constructed complex mathematical models that predicted the risk of mortgage-backed securities. These models were based on historical rates of defaults on mortgages; they assessed “risk” in the sense that Knight used it. But then occurred a huge drop in real-estate prices coupled with widespread fraud in approval of mortgages loans to unqualified buyers (“liar loans”) and fraud in the marketing of mortgage-backed securities. Investors realized that the analysts’ risk assessments were inadequate, and conditions of Knightian uncertainty prevailed. Investors then abandoned the market for other than the safest of investments, such as government bonds, and the value of non-governmental securities dropped precipitously.

An example of Knightian uncertainty will be given in the Case Studies.

Knight’s distinction between risk and uncertainty shows that there are several aspects to determining whether or not negligence—in particular, failure to exercise an appropriate standard of care—has occurred in an engineering failure. On the one hand, the failure may have occurred because the designers erred in calculating the risk. On the other hand, the failure may have occurred because of conditions of Knightian uncertainty—no one could have predicted the event that caused the failure; the required standard of care to prevent the event was unknown beforehand.

3.3 Act of God

Readers familiar with contract law might ask how Knightian uncertainty relates to the phrase “an act of God” that sometimes appears in contract language. The two concepts overlap somewhat but are not identical. The phrase “an act of God” in contract law refers to a significant event attributed exclusively to “natural phenomena whose effects could not be prevented by the exercise of reasonable care and foresight.” [7] Knightian uncertainty is much broader, including

acts of God but also acts of man and applies not only to destructive events occurring but also anticipated events *not* occurring.

4. Failure Investigations

When an engineering failure results in serious injury or death, usually an investigation of the causes of the failure is conducted. Ideally the investigation should produce a report that is, in the words of the Foreword to the report on the crash of the Concorde in 1989:

... intended neither to apportion blame nor to assign responsibility. The sole objective is to identify the causes of accidents or incidents and to prevent future

Thus even when the investigation should focus on how to improve safety, the investigation should focus on how to improve safety in advance of a possible tragedy.

4.1 Use of investigations

Not everyone who is involved in an accident, how to prevent future accidents, and the aim of learning from the accident, plaintiff's lawyers and the media are looking for publicity, and newsmen are looking for blame. Large corporations are often involved in lawsuits, and many are looking for money to settle lawsuits. Some accidents are based on examples of bad corporate behavior, and no identifiable villain, the media and the public are looking for someone to blame. Accident explanations are particularly suspect, because no blame can be assigned to someone who could foresee an unforeseeable event.

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What is relevant for our discussion of engineering failure is that the widespread desire to identify villains, when an accident occurs, has an effect on the media, juries, judges, and the general public. Leaders of engineering societies and state engineering-licensing boards live and work with non-engineer friends and neighbors, read the same newspapers, watch the same news broadcasts, and are affected by the general climate of opinion. The result is that despite attempts to exercise independent professional judgment, engineering leaders' opinions about what constitutes "the standard of care" and "ordinary prudence" can be influenced by public opinion and by the corresponding need to demonstrate concern for the public's well-being.

4.2 Punishment

If an engineer has been found to have acted negligently, punishment is usually administered through: 1) loss of license, 2) fines, 3) imprisonment, or 4) reputational damage. Reputational damage results from media coverage and from the actions of professional societies in issuing statements condemning the engineer's conduct and in expelling the engineer from the society.