To Engineer is Human by Henry Petroski

Reviewed by W. Brent Hall

A modern book on engineering could easily be filled with the many recent success stories of the field, ranging from space-age materials to artificial hearts. If the title were to include the word "human" it might also be expected to recount the social and economic benefits of engineering, or to describe the creativity of engineering and the satisfactions and pleasures of design.

This is not the book that Henry Petroski has written. Instead, his book deals with perhaps the most difficult aspect of the science and art of engineering to justify—the problem of failure. The long history of engineering successes is spotted with failures, and these failures seem to persist in the midst of, and in spite of, the most extraordinary advances. It is no wonder, then, that we engineers find it difficult to explain failures to a neighbor or a friend who is inquiring about the most recent engineering catastrophe. And when we try, how easy it is to fall into the trap of attempting a technical explanation. Fortunately, Dr. Petroski takes a different approach. He explains the elemental steps of the engineering process in everyday human terms, from goal-setting and planning to the putting of a plan into effect. In doing so he builds his thesis that to err in engineering is as human as in any other endeavor.

From the very first Dr. Petroski utilizes familiar human experiences to explain the nature of engineering. For example, in Chapter 2, "Falling Down is Part of Growing Up," he reminds us that we are all "engineers of sorts" who learn as children to hold our bodies against the forces of nature, and to walk despite and perhaps because of our failures. He quotes nursery rhymes to illustrate our childhood view of catastrophes and risks, and points out that somehow in growing older we have learned (false) not to expect failure in some things. An enjoyable illustration of flawed design is given in his recounting of the failure of his son’s electronic spelling toy. The letter keys of the toy began to fail roughly in order of their frequency of use in the English alphabet. He confesses to an initial lack of charity to the designers of the toy, despite his own understanding of the limitations of engineering, but describes how his son eventually took the faults in stride, preparing him for a lifetime of breakdowns and sometimes makeshift solutions. He concludes the early chapters with a delightful discussion of "The Deacon’s Masterpiece," by Oliver Wendell Holmes.

Chapters 4 to 7 describe the engineering process: design as a hypothesis of success, as foreseeing and obviating failure, and as planning and revision. Again, Dr. Petroski sprinkles his text with examples from everyday life, such as the planning of a trip, and from history, such as the development of metal bridges in the United States and Britain. The story of bridges is continued later in Chapter 13, "The Ups and Downs of Bridges," and is a particularly enjoyable one. Chapters 8 to 11 focus on accidents, safety, and causes of failure. The famous failures are discussed here, such as the Hyatt Regency Walkway and Tacoma Narrows failures. But also included are many less notable failures: crack propagation in the Liberty Bell and Big Ben, and fatigue of table knives and bus components, to mention a few. The author does a fine job of explaining in layman’s terms the concepts of risk and the safety factor, and how the engineer can reduce risks to ever smaller values but never to zero.

Just when the reader may be growing tired of failures, and perhaps finding it difficult to constantly see the positive side to the subject, the author provides a welcome respite in Chapter 12. Here he discusses the success of the Crystal Palace, built for the Great Exhibition in London in 1851 by Joseph Paxton. At this point in the book it is a joy to read how Paxton skillfully designed and constructed this great building, and how it became a wonderful success despite early criticism. The reader will leave this chapter, one of the most enjoyable in the book, with a great admiration for this man who was neither an engineer nor an architect.

The closing chapters of the book, Chapters 14 to 17, continue to look at what we can learn from failures and to illustrate how lapses, mistakes, and breakdowns occur. Included here is a case study of the first jet aircraft, the de Havilland Comet, as well as other examples of forensic engineering in which analysis of failures has led to improvements in design. But when we do not learn from past mistakes, future risks develop. Among the potential problems that the author sees is the computerization of engineering. His view is no reactionary response to the modernization of a profession; he makes a convincing case that dependency upon complex software, written by a small number of analysts and not by designers, carries significant risks. In the last chapter Dr. Petroski discusses the limitations of design, with its often conflicting objectives and constraints, and ends by describing a personal experience with a literary error in the quotation "Those who cannot remember the past are condemned to repeat it."

The book is not without flaws, but they are minor ones. Dr. Petroski’s arguments are sometimes so convincing that the reader accepts the inevitability of errors and is tempted to totally excuse them (a quite unintended result). For example, it is argued in the book that the price of doing something new is an increased risk of failure. Yet, while this is certainly true, there are many noninnovative types of human errors that are committed commonly and ought to be preventable. Achieving
control of human errors is an important topic that is barely touched upon in the book, perhaps because it has only recently become the subject of research. Another small problem with the book is that some of the themes of chapters verge on being repetitious. For example, the precepts that we can learn more from failures than successes, and that success is to foresee and obviate failure, both tend to recur throughout the text. Nevertheless, these are important themes and they provide a sound framework for discussing failures, so the repetitions are not minded.

Overall, the book is well written in a comfortable style that holds the reader's attention. It is replete with examples, illustrations, pieces of history, quotations from poetry and literature, cartoons, and anecdotes from the author's experience—all of it relevant and entertaining. Although the book concentrates mainly on structural and mechanical failures, it applies to all engineering design; the work “structure” in this book could represent almost any engineering creation. In short, this is one of the best books on engineering to come out in a long while. It belongs on the bookshelf beside “The Existential Pleasures of Engineering,” and kept within easy reach.

Now, when the neighbor or a friend asks for an explanation of the most recent engineering disaster, you and I will be ready, thanks to Henry Petroski and his fine book.

This book covers more than damping. It could be considered a primer in advanced structural dynamics. Damping is a subject that still continues to undergo a great deal of investigation. In the forefront for many years, the book’s authors have avidly contributed to the theory and applications of damping in aerospace structures and engines, automotive and other direct uses. This work is based on the authors’ own research and on other investigative work making this a standout book. As stated by the authors, “This book is written for individuals responsible for solving vibration and noise problems in a wide variety of industrial structures and machines. Practicing engineers . . . find here much valuable practical information as well as a strong theoretical framework forming a basis of applications of damping technologies in new and unfamiliar situations. Vibration control, in recent years (has) grown . . . from the solution of difficult, expensive, vibration problems in certain military aerospace systems into a widely used, often low cost element in the package of structural problems in the field of general engineering such as automotive, diesel engine, office, computer machinery and transportation system predictions.” The book contains an excellent section on nomenclature, six full chapters, and comprehensive design data sheets giving modulus properties as functions of temperature and frequency.

Chapter 1 opens the book by explaining, exploring, and defining the fundamental concepts in structural dynamics. This includes the methods of predicting response (differential equations of beams, classical normal mode theory) and discrete methods for simple structures. Damping is introduced in the discrete method which is then followed by a short description of receptance/impedance methods, transfer matrix (TM), and finite element (FE) approaches. The techniques for vibration control are partly art and partly science. The authors show the effect of mass, stiffness, and damping. They then introduce vibration isolation, noise control in enclosures and barriers, noise in machines and structures plus short, interesting discourse on fatigue of metals.

Chapter 2 characterizes the damping in structures and materials. The introductory section defines and derives log decrement, half power point method, and ratio of dissipated energy to stored energy. The previous three are measurements of the damping values. This leads into the subject of nonmaterial damping which discusses the effects of acoustic radiation damping, linear air pumping, coulomb friction damping with the accompanying derivation and approximate solution. We next investigate damping in materials, mechanisms of damping, high damping in certain alloys, damping in composite and viscoelastic materials, characterization of damping materials plus derivation of the equations for standard linear models and advantages. This incorporates the advantages and derivation of a generalized standard model. The book next considers the complex modulus, hysteresis loops, energy dissipation, relationships between the various models (extensional, shear, Poisson’s ratio) plus the relationship between harmonic and transient response. The chapter concludes with the examples of two-degrees-of-freedom systems with friction damping and calculation of transient response. An excellent chapter which should be thoroughly digested.

Chapter 3 describes the behavior and the typical properties of damping materials. Environmental factors (temperature, frequency, cyclic dynamic strain, static preload) are the most important in affecting damping properties of rubber-like materials. However, aging, oil, and high temperature exposure can also play an important role in the damping products. We can represent Young’s modulus for complex materials by including a loss factor. This is introduced into expressions where Young’s modulus and the loss factor can be derived for use in analytical modeling. Additional representations are temperature-frequency, superposition, frequency-dynamic strain effects, preloads effects, Mooney-Rivlin, where nonlinear strain effects can be factored into the equations. This provides general analytical representation expressions. The concluding section describes the measurement and analysis of the damping properties of materials. Again, another chapter that is well worth reading.

The preliminary information on damping representations and effects are now under our belt. The next chapter delves into the modeling of structural response of damped systems. Starting with simple and base excited single-degree-of-freedom systems with damping, this extends into force excitation with hysteretic damping with due consideration of the effects of real material behavior. The next section points out the calculation from half power bandwidth, response amplitude at resonance, Nyquist diagram which measures damping in a system as plotted in a complex plane. Hysteresis loops (stress versus strain in a material) plus damping determination from quadratic behavior for highly damping systems are the next topics. The equations for transient response are then derived. In this section, the solution of viscous damping and viscoelastic damped systems are formulated. The authors proceed with a very short discourse on random response including force and base excitation. We now forge ahead into the selection of steady state response of multiple-degree-of-freedom systems (MDOF). The well known beam equations using the classical approach is nicely explained with the accompanying normal mode method. The transfer matrix and its limitations together with finite elements are then picked up. Experimental nodal analysis follows but is very briefly discussed. The concluding section furnishes information on analysis of test data of a SDOF system with variable stiffness and damping.

Chapter 5 reports on the application of discrete damping.