Review of *The History of the Theory of Structures—From Arch Analysis to Computational Mechanics* by Karl-Eugen Kurrer

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Since the publication of Timoshenko's "History of Strength of Materials" in 1953, few books have attempted to provide a broader view on the beginnings and growth of structural engineering. Heyman's efforts at exploring advances in civil engineering led to the publication of a historical standpoint on structural analysis (Heyman 2004). About the same time, Becchi et al. (2003) published their "Essays on the History of Mechanics." Increasing interest in the history of structural engineering is evidenced by the organization of the first world conference on "Historical Perspectives on Structural Analysis" held in Madrid, Spain, in December 2005.

The recently published book by Karl-Eugen Kurrer examining "The History of the Theory of Structures" provides a fascinating and remarkable journey through concepts, connections, and controversies in the mechanics and theory of structural analysis. An earlier edition of the book, published in 2002 in German, was titled *Geschichte der Baustatik*. Kurrer divides the history of structural analysis into four distinctive periods: the preparatory period (1575-1825) beginning with Galileo and Hooke, followed by the contributions of Leibniz and Euler, and culminating with Coulomb; the discipline-formation period (1825-1900) which is attributed to Navier, Culmann, Maxwell, Winkler, Mohr, Castigliano, Müller-Breslau, and Kirpichev; the consolidation period (1900-1950) where structural analysis experienced a critical expansion largely due to the growth of reinforced concrete construction and later the development of shell theory; and finally the integration period (1950-present) spurred by the development and growth of the finite element method. Though the early period dates back only to the 16th century, Kurrer does not overlook the contribution of Archimedes to developments in statics through his understanding of the lever.

The book is composed of twelve engaging chapters. Following the introduction, we are presented with eleven introductory essays on topics ranging from statics to influence lines, from the displacement method to the paradox of the plastic hinge method, and from insights into the construction of viaducts to developments in bridge building. Chapter 3 seeks to understand the role of mechanics in the origins of fundamental engineering science. The writer contends that a "discourse between philosophy and the history of science" is essential to gain this understanding. The final building block in the development of mechanics was undoubtedly laid by Isaac Newton with the publication of *Mathematical Principles of Natural Philosophy* wherein Kurrer asserts that mechanics was separated from natural sciences. The theory and evolution of engineering science is believed to bring together contributions from diverse fields including system theory, general technology, and engineering philosophy and sociology. "The engineering science that evolved during the Industrial Revolution represents a specific developmental form of the relationship of the transformation of natural causality into technical finality and the inversion of this transformation."

It would interest readers to note that the first comprehensive book on applied mechanics was the three-volume "Handbuch der Mechanik" by Franz Ritter von Gerstner. Kurrer notes that Gerstner's breakdown of applied mechanics is implicitly energy based. Another important work in the 19th century is Weisbach's encyclopedia of applied mechanics, which was later translated into English (under the title *Principles of the Mechanics of Machinery and Engineering*) and several other languages. The publication of *Der Ingenieur* is recognized as the first engineering manual of its time containing rules, formulas, and tables for application in engineering. Weisbach is also credited with the founding of the first engineering journal by the same name. The other breakthrough publications of the era include Rankine's *Manuals* covering applied mechanics, the steam engine, and civil engineering.

Chapter 4 traces the development of arch structures, from the Ponte S. Trinità in Florence to the contributions of Baldi (1533-1617), the pastor Fabri (1607-1688), Charles Auguste Coulomb (1736-1806), the Spanish civil engineer Joaquín Monasterio, and Navier (1785-1836). The masonry arch still remains as one of the mysteries of ancient architecture and has fascinated engineers since Leonardo da Vinci. The end of the 16th century marked the beginning of a new era in masonry arch building, led by Roman architects. The limitations of the circular arch were soon overcome with larger rise to span ratios (the Ponte Vecchio in Rome has a rise/span ratio of 6.5). On the other hand, the wedge theory for masonry arches, founded by da Vinci, played a significant role in masonry arches for over a century. The theory of modern arch structures, though resting on the shoulders of previous giants, also benefited from the groundbreaking efforts of Winkler followed by Engesser and Müller-Breslau. Modern automation, however, now provides a basis (via the finite element method) for the analysis of most complex structures, including arches.

While mechanics before Galileo and Newton enabled the solution of simple but fundamental engineering problems, the Industrial Revolution provided the engine for the growth and application of mechanics in engineering practice. The beginnings of a theory of structures are explored in Chapter 5, wherein Dr. Kurrer traces the origins of strength of materials to Galileo's Discorsi. In 1678, about forty years after the printing of Galileo's dialogue between Salviati, Sagredo, and Simplicio, Robert Hooke publishes his seminal work on the theory of elastic deformation. As the Industrial Revolution spurred infrastructure engineering in Great Britain, investors saw the financial potential in road, bridge, and canal construction. The discipline-formation period is described in three phases starting with the constitution phase (1825-1850) and structural theory pioneered by Navier; followed by establishment phase (1850-1875), which saw the development of truss framework theory by Culmann, Rankine, Maxwell, and Cremona; and finally the classical phase (1875-1900) that laid the foundations of structural engineering through contributions of

Winkler, Mohr, Castigliano, Muller-Breslau, and Lord Rayleigh, among others.

Chapter 7 begins with a discussion of Saint Venant and advances in torsion theory and leads into developments in buckling theory led by Zimmermann (1845-1935). These insights were essential to the growth of the steel construction industry. Herein, Kurrer provides engineers with insightful information on the evolution of steel-concrete composite structures (which is shown to be as old as reinforced concrete) and lightweight steel structures. The development of three-dimensional space frameworks is the focus of the next chapter. Here we are introduced to the first prefabricated spatial tetrahedral framework designed by none other than Alexander Graham Bell. In Bell's assembly technique, formation and structural law materialize into a technological unit determined by function and form.

Advances in reinforced concrete (RC) and its influence in the theory of structural engineering are highlighted in Chapter 9. Kurrer regards the granting of a patent to a gardener from Paris (Joseph Monier) for the production of "movable tubs and containers for horticulture" using cement mortar with embedded iron as an "unsightly blemish on construction engineering history" given the fact that Joseph Lambot and Francois Coignet pioneered reinforced concrete concepts much earlier. Though Monier's understanding of the load-bearing ability of reinforced concrete was inferior to that of Coignet and Thaddeus Hyatt (who received the first American patent in 1878 for his idea to use iron on the tension side of concrete), he did pave the way for future achievements in reinforced concrete. Another notable section of the chapter discusses the contribution of Emil Mörsch to developments in strut-and-tie modeling for RC design. In chapter 10, Kurrer presents the transition from classical mechanics (that provided engineers the tools to solve structural problems by hand) to modern structural theory that is intrinsically linked to the emergence of the computer age.

Twelve scientific controversies in mechanics and the theory of structures, which comprise the contents of chapter 11, make for engaging reading. Kurrer begins with Galileo's *Dialogo dei Due Massimi Sistemi del Mondo* (Dialog Concerning the Two Chief World Systems) and *Discorsi e Dimostrazioni Matematiche, intorno a Due Nuove Scienze* (Dialog Concerning the Two New Sciences). The former confirms the rationale for the heliocentric system over the Ptolemaic model, whereas the latter undermines the foundation of Aristotelian natural philosophy. In 1686, following a statement by Leibniz on Descartes, God, and the preservation of motion, a philosophical debate on the "true measure of force" raged on for more than half a century. Equally interesting is the debate that pitted theorists against practitioners when three mathematicians calculated the horizontal thrust of the dome of St. Peter's in Rome and recommended installing a second tension ring. In response, Giovanni Poleni proclaimed that "if the dome…could be conceived, drawn and built without mathematics (recall that Michelangelo was not trained in mathematics),…then it should be possible to restore it without the help of mathematics." However, it is generally acknowledged that the structural report by the mathematicians for the analysis of St. Peter's dome constitute the first ever set of "structural computations." Kurrer follows this information with discussions and developments in elasticity theory (involving legendary figures such as Navier, Cauchy, and Green) and the conflict between graphic statics and prescriptive graphical analysis. The criticism of Terzaghi's consolidation theory by Fillunger led to a scientific commission investigating the matter and concluding that Fillunger himself had made a mistake when disputing the derivation of his rivals. After realizing his mistakes, Fillunger was driven to depression and claimed his own life. The next controversy is attributed to an article by Pöschl, who comes to the conclusion that the principle of virtual displacement leads to different conclusions "depending on whether the problem is a standard one involving elastic equilibrium or one involving buckling." The chapter concludes with the most recent (1961-1962) dispute between Stüssi and Thürlimann over the ultimate load method. While the writer's classification of the types of controversies is somewhat dreary (the need to compartmentalize such facts is not particularly useful or worthwhile), the information presented in the chapter is both interesting and thought provoking.

The book concludes with the author's introspective examination of modern developments in structural engineering. He endeavors to show that beauty and utility in a building structure are compatible, that aesthetics can be embodied in structural analysis and that computer-aided graphical analysis may serve to minimize the antagonism between architects and structural engineers. The book also makes connections between theories of structural analysis and progress in construction engineering. Among other interesting observations, Kurrer notes that modern steel structures are evolving into system-based construction, which incorporates not just theory and testing, but also includes preservation and recycling. Similar developments are also evident in concrete construction as society becomes increasingly aware of global issues related to the depletion of natural resources and consequences of deterioration.

The book is filled with superb illustrations, photos, and pictorials of covers dating back to the 1800s. For example, the visual of Koenen's design theory for reinforced concrete that appeared in the Monier-Broschüre in 1886 is still fascinating though we have all seen the modern variation of the Whitney stress block in every recent edition of reinforced concrete textbooks. The book also contains 175 brief biographies of important figures in structural mechanics and engineering. Finally, Kurrer's plea to consider a historic-genetic approach to teaching structural engineering should not go unheeded. Ultimately, this is an extraordinary book that should be in every engineering library and on the bookshelf of every structural engineer who aspires to make a difference in the design, development, and preservation of civil infrastructure.

References

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