

Karl-Eugen Kurrer: The History of the Theory of Structures. From Arc Analysis to Computational Mechanics

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Piero Villaggio

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Interest in the history of structures arose only after the second half of 20th century when the discipline—in obedience to the celebrated Hegelian passage on Minerva's owl—had reached a deep degree of maturity. This new trend was marked by the publication of two important works: Timoshenko's "History of Strength of Materials" (1953), and Truesdell's "The Rational Mechanics of Flexible or Elastic Bodies" as an introduction to one of the volumes of Euler's *Opera Omnia* (1960). The two books are complementary. Timoshenko embraces the period from 1638 to 1950 describing with his congenial clarity all aspects of the evolution of the discipline, from its mathematical foundations to its technical applications. Truesdell analyzes a shorter interval of time, from 1638 to 1788. He considers only one-dimensional bodies like strings and beams, but neglects the engineering realizations that were nevertheless remarkable. His style is magmatic, his prose erudite, and his position constantly impassioned in judging the protagonists of his history.

A third book on the history of structures was published by Gordon with the title "Structures, or Why Things do not Fall Down" (1978). The purpose of the book is merely expository, but its appealing choice of subjects, its brilliant style, its simplicity, have attracted

the attention of a multitude of scholars extraneous to mechanics of continua.

A fourth original contribution to the knowledge of history of structures was offered by E. Benvenuto in his textbook "*La Scienza delle Costruzioni e il suo Sviluppo Storico*" (Strength of Materials and its Historical Development) (1981). Benvenuto, engineering, professor and humanist, wrote an innovative university text for engineering students where mathematics, mechanics, history, and extraordinary hand-made drawings are suggestively intermingled.

Now the literature is enriched by this Thomistic *Summa* written by Kurrer, which presents a colossal attempt to unify the knowledge and the tastes of his predecessors. The book is introduced by an enthusiastic foreword of Ramm who, praising the author for his highly subjective impressions, makes some personal comments on the discipline. His position is however ambiguous. From one side he rightly affirms that structural mechanics was never the discipline of "number crunchers," on the other side he seems to share the false and demagogical statement of Argyris that "computers shape the theory."

The monumental book of Kurrer (848 pages) consists of twelve chapters. The first is a short account on recent books and dissertations on the history of structures. The chapter ends with the impassioned, but utopian, message that the divulgation of science should stimulate social discussion about the means and aims of science. The second chapter proposes an

P. Villaggio (✉)
Dipartimento Ingegneria Strutturale, Università di Pisa,
Via Diotallevi 2, 56126 Pisa, Italy
e-mail: m.venutelli@ing.unipi.it

articulated subdivision of the successive stages of the development of the theory from 1575 to date. The chapter is inhomogeneous because, unexpectedly, the reader finds a description of lever's principle, parallelogram of forces, and a compendium of engineering education in the world since the institution of the *École Polytechnique* in France. Then the chapter contains some examples of calculus of frameworks with the second order theory and an appeal to beauty in structures. For precision's sake, Plato died in 347 B.C. and never wrote a *Politeia*!

The subsequent third chapter, anticipated by a quotation of Newton's axioms and a reproduction of the universally known Culmann's crane, starts with the peremptory, but disputable, statement that only after 1900 engineering science acquired an independent gnosiological state. Jacob Bernoulli, Euler, Kirchhoff, would protest. Then there is a sudden elenctic discussion of three questions raised by H. Rumpf on science. These are too generic for being constructive. The chapter ends with a short review on engineering handbooks published during the 19th century and here, finally, we find a collection of precise data not recorded elsewhere.

Chapter 4, one of the most interesting of the book, is dedicated to the theory of arches. The author rightly begins saying that the masonry arch is still one of the mysteries of architecture and continues by proposing a definition of masonry arch as a structure realized by assembling rigid blocks with negligible tensile strength. Then, after a brief, but perhaps useless, overview on some historical bridges, we find an effective description of the four main theories formulated for masonry arches conceiving the arch as: (1) an aggregate of smooth wedges; (2) an aggregate of rough wedges; (3) an elastic beam; (4) a perfectly plastic beam. Unfortunately the "epistemological" conclusion is cloudy because it stems on some questioned scientific criteria proposed by Bachelard.

Chapters 5 and 6 are instead more incisive. The beginning, to be frank, is not very exalting for it repropose the traditional hagiographic figure of Leonardo which was demolished by Dijksterhuis and Truesdell. At defence of the popular Leonardian adulation Kurrer invokes the recent rediscovery of the Codices of Madrid. But a more careful exegesis of the manuscripts has confirmed Dijksterhuis's and Truesdell's discredit of Leonardo's discoveries. In these pages C. Wren is quoted and the coincidence of the year

of his birth (1632) with the publication of Galileo's "Dialogue." Perhaps another coincidence might have been noted, namely that Newton was born in 1642 (not 1643!), the year of the death of Galileo. In the following pages we find a long and new account on the life and work by Gerstner. Gerstner was known only for his theory of waves (quoted by Lamb), but his contribution to statics of beams was ignored for two centuries. His "load bearing" method anticipates the recent discretization procedures. Then we find an accurate account on the contributions of Eytelwein and Navier on the theory on continuous beams. The subsequent Chapter 6 is by far the most appealing in the book. It starts with an ample overture on the socio-political conditions of Europe after 1815. This may seem useless in a history of a scientific discipline, but, at the contrary, it explains the dissolution of the *École Polytechnique* and the flight of some eminent French scholars like Clapeyron and Lamé to St. Petersburg. The subsequent part of the chapter presents a resumé of the contributions of scientists who marked the astonishing progress of the theory in the second half of 19th century: Culmann, Cremona, Mohr, Maxwell, Castigliano, Müller-Breslau. In these pages we find a detailed resumé of a controversy between Mohr and Müller-Breslau on how to model a beam, either as a truss or as a one-dimensional continuum. Another interesting, not enough known, debate is that between Hertwing and Weingarten on Castigliano's theorems. The final pages of the chapter contain an account on the vicissitudes of Schleicher after the Second World War. Schleicher, as a member of the Nazi Party, was removed from his position in Berlin. This fact is relevant because it testifies the courage of post-war Germany in condemning all her citizen involved in the Nazi Regime, even illustrious personages like Schleicher and W. Furtwängler. Other countries were not so coherent. For instance, the mathematician and historian Giorgio Israel shows that all Italian Fascist professors maintained their chairs and often "viscously" hindered the rehabilitation of their Jewish colleagues banished by the former regime.

Chapter 7 is rather disconnected. It starts with a reexposition of Saint-Venant's torsion theory, which is contained in all lecture notes for engineering students. Then there is an unexpected shift to the construction of cranes, crane hooks (with omission of the rigorous Fillunger's theory), a return to the shear centre, an excursus on steel constructions, and the rise of the first Standards Committee for Steelwork.

Chapters 8 and 9 are again inhomogeneous. They offer an ample description of steel and concrete structures built from 1850 to 1950. The numerous photos are often accompanied by schematic drawings and hints on the methods of calculation. The reader notes a strong difference in attitude and style with respect to Chapters 5 and 6. The admirable amount of theoretical data recorded there is here absent or brutalized in few pages. Foppl's condition is discussed in a half page, the theories of plates and shells, despite of their importance, are restricted to a few historical mentions. The theory of in-plane loaded slabs is ignored. Another regrettable fault is the absence of any mention to the theory of two-dimensional plane systems by the complex variable method. Since 1909, the year of publication of Kolosov's paper, engineers could solve with extraordinary elegance difficult problems like, for instance, the stress state around polygonal holes, elastic contact problems, and optimum shapes of plates.

Chapter 10 narrates the development of the theory of structures from 1950 to date and, unavoidably, discusses the vexed debate about the introduction and abuse of computing machines. The chapter starts with an original question: why, differing from pure mathematics and rational mechanics, structural mechanics made, since its beginning, a so heavy recourse to figures and graphic procedures? The answer, sustained by some smoky sentences of Günter Anders and a much more logical argument of Sybille Krämer, is that a specific symbolic language, as the use of hieroglyphic messages like figures, may be effective for conveying science, like algebra and tensor calculus. A subsequent paragraph "The contribution of mathematical elastic theory" is highly questionable. Kurrer criticizes Love's Treatise saying that his mathematical theory is purely academic and not a practical discipline useful for engineers. These statements seem to ignore that Love's book dedicates large space to the approximate theories of beams loaded by body forces, of moderately thick plates, of edge-effects in shells, and other similar cases. In the subsequent section we find an incorrect formulation of the second boundary value problem of elasticity because the six Beltrami-Michell equations are not uniquely solvable once surface tractions are prescribed. The subject is then shifted to the approximate methods for calculating pin-jointed trusses and rigid-jointed frames. This section is one of the most important. With stupefying abundance of historical details Kurrer narrates the evo-

lution of these methods from Clebsch to Grinter, illustrating the contributions of Bendixsen, Gehler, Ostfeld, Cross, and many others, less known, as Mann and Zuse. The final part of Chapter 10 treats the diffusion of numerical procedures for solving structural problems. The author rightly says that these techniques stem from two branches of mathematics: matrix theory and variational principles. But he seems too optimistic when he claims that matrix analysis is a means for new discoveries in natural and engineering sciences. And even more exaggerated is the assertion that computational mechanics, not only reformed structural analysis, but enabled the construction of new kinds of cognitive objects. As far the variational principles, Kurrer correctly emphasizes the importance of Green's and Castigliano's principles on minimum strain and stress energies respectively, but puts on the same level of relevance an extremum principle due to Hellinger-Prange-Reissner. From a mathematical and computational point of view, only the first two are theoretically consistent. Occasionally, why in a so well documented book the date of birth of Kant (1724) is mistaken?

The 11th chapter collects some celebrated controversies in history of mechanics, from Galileo's astronomy to plastic analysis. Information of this kind is welcome, but why have they not been inserted into the text as several other controversies? For exactness, the first "controversy" should be named a "submission."

The 12th and last chapter discusses the relationships between Aesthetics and Theory of Structures. The only interesting part of this vague and fragmentary chapter is an effective compendium of A.G. Meyer's book "*Eisenbauten. Ihre Geschichte und Ästhetik*", published posthumously in 1907.

Kurrer's treatise does not end here. In Svetonian spirit it is completed by the collection of short biographies of several men who gave outstanding contributions to the development of this fascinating branch of mechanics. And we realize that they were men like us.

At the conclusion of this retrospective journey through the birth and growing of theory of structures we ask what the general impressions are and comments a reader may express after the committing effort of having followed Kurrer's enterprise. A tentative list might be the following:

(1) An encyclopaedic work of this extension and completeness has never been published before, and one is amazed that it has been the fruit of the culture and the patience of a single scholar. (2) E. Ramm, in

his Foreword, praises the subjectivity of Kurrer's judgments. On the contrary, we observe that he avoids taking precise positions by declaring what is important or marginal, right or wrong, in each author. The opposite extremum is constituted by Truesdell, who does not hesitate to write sentences like this: "Here Pearson (*op. cit. ant.*, p. 11, §30) shows his usual ability to miss the point of theoretical papers" (Truesdell's History, p. 115). The Italian philosopher Benedetto Croce claimed that historians who do not critically interpret the facts of the past are simply chroniclers! (3) The dy-

namics of structures and structural optimization, two branches of the discipline associated to the names of Tredgold, Saint-Venant, F. Neumann from one side and those of Maxwell and Michell from the other, are completely neglected. There is now a fervent theoretical and numerical activity on these problems. (4) The book offers an excellent account on the theories of beams. The occasional references to the theory of elasticity are sometimes incorrect. The frequent epistemological digressions are superficial and questionable.