Physical Models: Their historical and current use in civil and building engineering design

A review by **Hans-Wolf Reinhardt**

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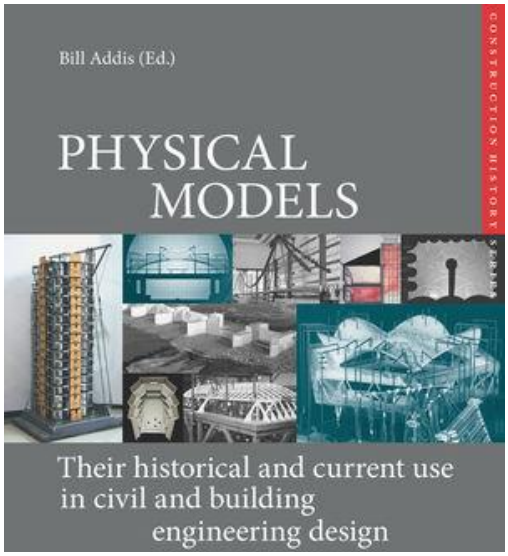

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When you dip into the book for the first time, the wealth of information seems almost overwhelming. But when you take a second look, you see that the material is cleverly laid out in manageable chunks, referred to here as sections, arranged in chronological order. These sections are preceded by a preface by the editor Bill Addis, who with characteristic English understatement explains that the book only scratches the surface of current knowledge and that there is enough material in each section for several dissertations. The reader soon discovers that this book delves far more deeply into the subject than the editor maintains.

Content-wise, the book begins in the first chapter of Section A with physical models from ancient times to the 1880s. Here you will find such illustrious names as Vitruvius with his Ten Books on Architecture, Hero of Alexandria with his technical inventions, Brunelleschi with his model of the dome of Florence Cathedral, da Vinci with his proposals on structural engineering, Palladio with his treatise on architecture, Galileo on the weakness of giant structures, Fontana on the erection of the Vatican obelisk, Elias Holl with his collection of scientific instruments in Augsburg, Grubenmann and his models of timber bridges over the Rhine and Smeaton with his design of the Plymouth lighthouse.

The next chapter focuses on the block models of masonry arches and vaults designed by Hooke and Wren, Rondelet, Young and Pippard to name a few, which contributed to the understanding of masonry under compressive loading. The following chapter in this section delves into catenary architecture and components under tensile stress. Here we are introduced to Poleni's hanging models for the dome of St Peter's Basilica, Kulibin's model of the Bridge over the River Neva, Gaudi's model of the Sagrada Familia and Gösling's model of the Reichstag dome. Most of these models were used to mirror the catenary curve for domes under compressive loading. The next chapter is devoted to the works of Leonhard Euler and his innovative bridge calculations, and also references Musschenbroek's buckling tests. The two following chapters provide an in-depth study of the Telford, Buchanan and Dredge models of British suspension and tubular bridges, going into the design in great detail. Thoughts on the model scale and their similarities can also be found here.

Part B is devoted to models used in structural design from the 1890s to the 1930s. The first chapter deals with the wide-ranging British debate on the stability of masonry dam structures. It concludes that the previous empirical approach would have resulted in a more reliable estimation. The next chapter looks at the scientifically based design of the Boulder Dam in the USA, which involved large-scale model studies. Thin concrete shells are the subject of the following chapter, beginning with the Zeiss-Dywidag shells in Jena. The works of Dischinger and Finsterwalder, who are regarded as pioneers of this construction method, is examined in great detail. The next two chapters look at model testing in Italy during the interwar period and the works of Torroja in Spain. Models of dam walls and wide-span load-bearing structures were constructed to measure deformation, deflection and force. Next comes photoelasticity, which has an entire chapter to itself. Based on stress-induced birefringence, this method made it possible to evaluate the stress state inside components.

Section C deals with models used in structural design from the 1940s to the 1980s. It starts with a chapter on model production and modelling techniques. Early attempts at electrical strain measurement, as well as acoustic and other methods are discussed. It also outlines the practical application of dimensionless numbers and Buckingham's π Theorem. The MPA (Materials Testing Institute) in Stuttgart, the ISMES in Bergamo and the LCEMC in Madrid each have their own dedicated chapter. Work on models in Stuttgart was initiated by the Graf-Leonhardt-Schächterle trio in conjunction with the construction of the *Reichsautobahnen* road infrastructure project and the associated bridges, especially over the Rhine. The Institute for Photoelasticity and Model Measurement – the only university institute of its kind in Germany – was founded there much later, in 1953. One part of this chapter vividly describes the activities of Frei Otto, who designed the shape of tensile cable net structures with the aid of minimal surface areas formed by soap suds. The ISMES founded in 1951 carried out detailed modelling of dam walls, as well as studying the behaviour of high-rise buildings under static and wind load and unusual tall structures such as churches and sports halls. The LCEMC Central Institute began with photoelastic models, then went on to models made from reinforced micro-concrete, which were used to study above-ground structures as well as dam walls. The name Torroja is closely associated with this research – a resourceful and extremely hands-on engineer who founded and directed several institutions.

At its monastic-like research station in Wexham Springs in the UK, the Cement and Concrete Association focussed not only on material development; it also conducted important modelling studies involving bridges, cooling towers, churches and wide-span shells, especially under Rowe's leadership. The next five chapters deal with notable personalities or individual projects. Hossdorf used acrylic and epoxy resin, wood, aluminium, steel and micro-concrete for his models, depending on the parameters under investigation. He used micro-concrete to study crack formation and the other materials to model elastic behaviour, while aluminium or steel tended to be used for plastic behaviour. Frei Otto was particularly interested in experimenting with soap bubbles, which, as already mentioned, assume minimal surface areas. His research was unparalleled and always inspirational. Musmeci also used soap bubbles as well as rubber models to study the behaviour of unusual bridge structures and obtained similar results to Otto, although neither was aware of the other's work initially. Isler developed the shapes of his free-form shells using frozen cloth. He was an ardent advocate of models, unlike Torroja or Dischinger, who approached tasks from an analytical perspective. A whole chapter is dedicated to the Multihalle in Mannheim. The timber lattice shell with 60 m spans – still the only structure of its kind in the world – was modelled in a variety of ways.

Section D looks at modelling techniques for non-structural problems, such as wind tunnels, shaking tables to simulate earthquakes, acoustics and geotechnical centrifuges. In addition to the spatial coordinates, time is now factored in, and with it, inertial force. This section starts with the history of hydraulic modelling studies in France, England, the USA, Switzerland and other countries. Then it moves on to early wind tunnels, which were used to visualise wind flows and eddies, and also to measure wind loads, resonance and vibration in bridges. Next comes a chapter on shaking tables, which started out with one degree of freedom and now have up to six degrees of freedom. The acoustic design of concert halls, churches and recording studios was first addressed towards the end of the 19th century and has been continually improved. Inertial forces are generated by the acceleration of mass, which is applied in centrifuge models for geotechnical studies. The development started in the 20th century in the USA and the USSR using British proposals from the 19th century.

Section E looks at 21st century projects in a format that is just as instructive and diverse as the previous sections; some of these projects are directly connected to earlier chapters, for example the design of civil engineering structures and complex brick buildings, hydraulic questions, boundary layer investigations in the wind tunnel, shaking tables and centrifuges. Biomimetics, i.e. the use of biological models to emulate plant movements in technical systems, is a new topic. During the last third of the 20th century, model construction was almost entirely superseded by the advent of computers and the use of finite elements, although it is still an important component for architects and engineers.

The 39 individual chapters of the book have been compiled by 31 specialist authors, seven of them by the exceptionally accomplished editor. One particular appeal of the book is the shear variety of topics covered, making it both a useful source of information and a good read. References are included at the end of each chapter, while at the end of the book is a meticulously compiled index, preceded by a biography of each of the authors. Illustrations are included to enhance the text. This is the first time that the full spectrum of modelling has been covered in a single book, as Werner Sobek states in his foreword. Editors of the Construction History Series Karl-Eugen Kurrer and Werner Lorenz can count themselves very fortunate to have signed up such a leading authority as Bill Addis. One would hope that the book is widely distributed, as it certainly deserves a place in any technical library, as well as the private libraries of anyone with an interest in architecture, science and construction.

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