Dipartimento di Ingegneria
Strutturale e Geotecnica

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Dottorato in
Ingegneria Strutturale e Geotecnica

PROGRAMMA ATTIVITA' DIDATTICA A.A. 2016/17

DOTTORATO IN INGEGNERIA STRUTTURALE E GEOTECNICA

STRUCTURAL DESIGN FROM EMPIRICAL TRADITION

Lecture Series by
Thomas E. Boothby, Ph.D., P.E., R.A.
The Pennsylvania State University

Visiting Professor
Sapienza University of Rome

Abstract

"In the interaction between theory and practice, science has again and again been in the position of debtor, drawing on the craft tradition, and profiting from its experience rather than teaching craftsmen anything new."

Stephen Toulmin and June Goodfield (1982)

In this series of lectures, we will investigate the structural design methods of the craft tradition, which are wholly empirical, and how these methods interact with the science-based design, which is almost wholly rational.

In the first lecture, we will investigate what these terms, especially 'rational' and 'empirical', mean from a philosophical point of view and then from an engineering point of view. In particular, we will explore how philosophical empiricism and rationalism are manifested in empiricist design and in rationalist design. We will show that even rationalist methods of design require empiricist corrections and will further demonstrate the empiricist basis of all structural design.

In the second lecture, we will look in detail at the wholly empirical design methods used by builders through the nineteenth century. Any structure earlier than the eighteenth century is surely designed empirically, while engineers and builders continued to resort explicitly to empirical design through the end of the nineteenth century. We will discuss in as much detail as possible the forms of empirical design used during these time periods. The earliest methods of empirical design involve proportioning rules that were simultaneously applied to engineering and architectural design. Other forms of empirical design followed, including prescriptive rules, graphical methods, standard designs, and scaling larger structures on the basis of smaller efforts.

In the third lecture, we will investigate the continuing use of empirical design. Having shown in the first lecture that rationalist methods of design require empiricist corrections, we will give further examples of how these corrections are made in wood, reinforced concrete, steel and masonry design.

We will also point out a few instances of wholly empiricist design, dating from the mid-twentieth century through the present time.

In the fourth lecture, based on a series of case studies, we will point out a number of flawed preservation efforts that resulted from attempts to apply rationalist design to the rehabilitation or strengthening of historic structures. Having established the legitimacy of empirical design in the previous lectures, we will describe how empirical design is a better alternative and describe other cases where empirical design has been successfully applied to the treatment of historic structure.

The entire series will make the argument that empirical design is based on a philosophically defensible view of the behavior of structures and should be recognized as on an equal footing with rationally based design, especially regarding the treatment of historic structures that were designed by empirical methods.

Program

- Monday 12 June 11.00-13.00:
  A Reasoned Approach to Empirical Design
- Thursday 15 June 11.00-13.00:
  Empirical Design through Rankine
- Monday 19 June 11.00-13.00:
  Modern Examples of Empirical Design: Trial and Error as a Modern Engineering Method
- Thursday 22 June 11.00-13.00:
  The Good, the Bad, and the Ugly: Case Studies in Historic Preservation from the USA

Speaker Bio

Thomas E. Boothby is Professor of Architectural Engineering at The Pennsylvania State University. He has been in this Department continuously since 1992. He has a B.A. in Architecture from Washington University (St. Louis), and an M.S. from the same institution. He earned a doctorate at the University of Washington (Seattle) in 1991. He has ten years of experience working for consulting engineers and architects, both before and after his formal training in engineering. Dr. Boothby's research specialty has been the investigation and assessment of historic structures. Following his significant contributions to the management of masonry arch bridges, he has become interested in the methods used for structural design in previous centuries. He has authored a book *Engineering Iron and Stone*, published in 2015 by the ASCE Press, and currently has a textbook on empirical design under contract to Thomas Telford Press.

Professor Boothby is a Registered Architect and Professional Engineering and is a Fellow of the American Society of Civil Engineers and the Structural Engineering Institute

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Roma, 2 maggio 2017

Civil Engineering

In the late 1800s

new design opportunities to serve business and transportation abounded, and the civil engineering profession responded with efficient design methods to meet the surging demands.

Engineering Iron and Stone: Understanding Structural Analysis and Design Methods of the Late 19th Century presents a comprehensive explanation of the empirical, graphical, and analytical design techniques used during this period in the construction of both large and small buildings and bridges in wood, stone, brick, and iron. Drawing on a career-long fascination with how structural engineers do their work, Thomas Boothby provides specific examples of these analysis and design methods applied to arches, girders, trusses, beams, and columns. The numerous calculations, drawings, and photographs, both historic and contemporary, illustrate the application of these techniques to a wide range of structures.

While major civil engineering works of the Gilded Age are acknowledged, Boothby focuses on the smaller, more ordinary local projects that today's engineers might encounter and analyzes the significant body of engineering design that went into their construction. Boothby also points out the historic value in preserving the engineering techniques and ideas of that era. The rapidity of computation and the intimate relationship between the structure and its analysis have been lost in the numerically intensive analytical methods currently employed.

Undertaking the historic preservation or rehabilitation of structures from the late 19th century can be challenging. However, understanding the original design intent can aid in a successful outcome. The quick and computationally efficient methods described in this book can assist present day engineers in understanding the behavior of these structures and give insight into their actual performance.

About the Author

Thomas E. Boothby, Ph.D, P.E., R.A., is a professor of architectural engineering in the Department of Architectural Engineering at the Pennsylvania State University, where he has taught since 1992. He has written numerous journal papers and is currently researching the history and application of empirical design.

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Boothby

Engineering Iron and Stone

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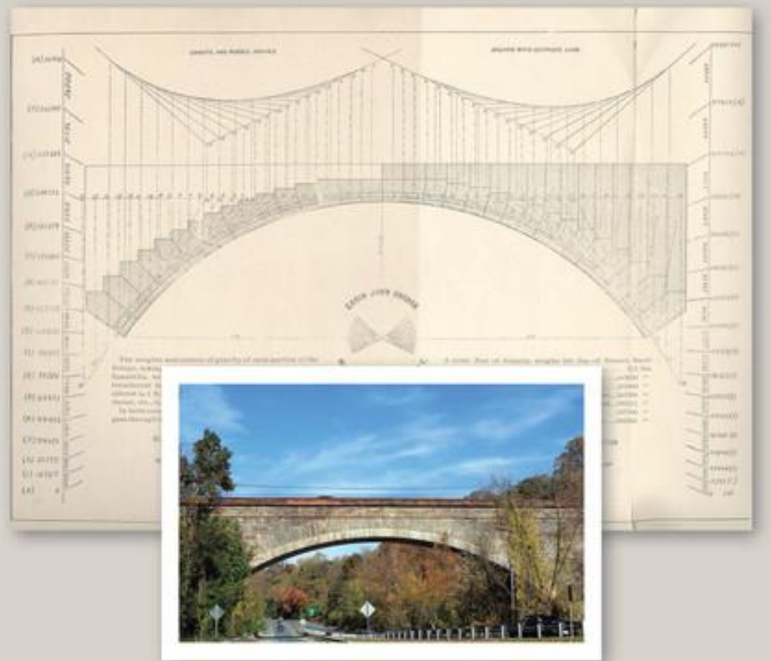

Engineering Iron and Stone

Understanding Structural Analysis and Design Methods of the Late 19th Century

Thomas E. Boothby, Ph.D., P.E.

ASCE PRESS

BONUS TRACK

Monday 12 June 14.00:15.00

SUSTAINABLE TECHNOLOGIES FOR STRENGTHENING MASONRY STRUCTURES

Gianmarco de Felice

The recent earthquakes have shown the vulnerability of masonry structures pointing at the necessity to develop sustainable strengthening techniques. Innovative systems consisting of high strength textiles made of either glass, basalt, carbon or steel cords embedded into a mortar matrix and externally bonded to the masonry structures are receiving a great attention both in the scientific literature and in the current practice. The rapid diffusion of these systems for seismic retrofitting however is not associated with an appropriate knowledge of their mechanical properties and their efficacy in increasing the seismic capacity of existing structures. The present talk will provide an overall view on the possible application of these systems: referring to on field application and recalling recent experimental outcomes, pros and cons on the use of mortar based composites for strengthening masonry structures under both design loads and seismic action will be critically discussed.

<u>Bio</u>
Gianmarco de Felice is professor of structural engineering at the Department of Engineering of *Roma Tre University*, where he coordinates the *PhD school in Civil Engineering*. He is chairmen of the RILEM Technical Committee TC-250 CSM "*Composites for Sustainable strengthening of Masonry*" and of the ACI Liaison Committee 549-0L "*Thin Reinforced Cementitious Products and Ferrocement*". He has been the scientific coordinator for the design of engineering projects on heritage conservation, such as the restoration of *Abbey of San Clemente in Casauria* supported by the *World Monuments Fund* and awarded by the *Domus International Prize*. His current research encompasses the structural performance of architectural heritage, the seismic assessment and retrofitting of masonry and reinforced concrete structures, the modelling of soil-structure interaction due to excavation, the mechanical characterization of composites and the development of sustainable technologies for seismic strengthening.

Thursday 15 June 14.00:15.00

COMPUTATIONAL MODELING OF MASONRY STRUCTURES

Elio Sacco

The development of adequate stress analyses for masonry structures represents an important task not only for verifying the stability of masonry constructions, as old buildings, historical town and monumental structures, but also to properly design effective strengthening and repairing interventions. Thus, several numerical techniques, based on different modeling approaches, have been developed to investigate and to predict the behavior of masonry structures. Micro-models consider the units and the mortar joints separately, characterized by different constitutive laws; thus, the structural analysis is performed considering each constituent of the masonry material. The mechanical properties that characterize the models adopted for units and mortar joints, are obtained through experimental tests conducted on the single material components (compressive test, tensile test, bending test, etc.). Micro-macro, i.e. multiscale, models consider different constitutive laws for the units and the mortar joints; then, a homogenization procedure is performed obtaining a macro-model for masonry that is used to develop the structural analysis. Even in this case, the mechanical properties of units and mortar joints are obtained through experimental tests. Macro-models, or macroscopic models, are based on the use of phenomenological constitutive laws for the masonry material; i.e. the stress-strain relationships adopted for the structural analysis are derived performing tests on masonry, without distinguishing the blocks and the mortar behavior. The micromechanical, the multiscale and the macromechanical approaches are presented, giving some details for specific models proposed in the last years. In particular, the discussion is limited to models (micro, micro-macro and macro) framed in the 2D small strain and displacement approach.

<u>Bio</u>
Elio Sacco (ES), full professor of "Scienza delle Costruzioni" (Solid and Structural Mechanics) at the Dep. of Civil and Mechanical Engineering of University of Cassino and Southern Lazio.
RESEARCH FIELDS AND ACTIVITY: mechanics of structures and materials, with particular reference to theoretical and computational problems relevant to nonlinear material responses:
Material constitutive modeling: static and dynamic response for cohesive and ductile materials, advanced materials (shape memory alloys); micromechanics and homogenization techniques: analysis of composite materials characterized by nonlinear behavior of the constituents; multiscale analysis of heterogeneous structures: structural analyses developed considering different scales, i.e. the scale of the structure and the scale of the material; mechanics of masonry materials and structures: development of specific constitutive laws, computational procedures for the analysis of masonry structures; analysis of plate and shells: development of models and finite elements.

Thursday 19 June 14.00:15.00

EMPIRICAL DESIGN IN HISTORICAL CONSTRUCTIONS AFFECTED BY THE 2016-2017 CENTRAL ITALY SEISMIC SEQUENCE

Luigi Sorrentino

The recent seismic sequence in central Italy caused a tremendous impact on historical constructions, with most of victims meeting their fate in unreinforced masonry structures. The dramatic toll could have been even worse if the most severe event of the sequence had occurred as first and at the time of Masses. The areas affected by the sequence have undergone seismic activity over the centuries, hence a number of solutions were developed to try to improve the earthquake performance. Some of them are of sheer interest, considering the difference in outcome between Amatrice and Norcia. The latter historical centre was among the first to experiment a seismic building code, after the 1859 event. Nonetheless, whereas ordinary masonry buildings, also thank to later strengthening, displayed an acceptable performance, churches have shown systematic collapses. Observed counterintuitive behaviours, such as the survival of tall towers or slender plane belfries, will be interpreted based on recorded ground motion and specific models. The devastating response calls for a rethinking of intervention strategies, both post event and preemptive, frequently beyond the field of structural engineering and architectural restoration.

Bio

Luigi Sorrentino has got a PhD in Structural Engineering from Sapienza - University of Rome, where he is currently Assistant Professor. Since its establishment, he has been involved in the research projects of the Earthquake Engineering University Laboratories Network (ReLUIS). He has participated to scientific exchanges with academic and research institutions in Europe, Australia, Chile, China, New Zealand and USA. His research interests are focused mainly on the seismic performance of masonry structures. He is reviewer of international journals of earthquake engineering. He is member of the Working Group 1 for the revision of EC8 – Earthquake Resistant Constructions. In 2017 he has been awarded the Associate Professor qualification in Structural Engineering.

Monday 22 June 14.00:15.00

DYNAMIC CHARACTERIZATION AND HEALTH MONITORING OF HISTORICAL BUILDINGS

Annamaria Pau

Some years ago, a series of experimental tests including the recording of the ambient vibration response has brought under its purview some of the most important monuments of Rome because of their proximity to the new underground line under construction. The availability of these data made it possible to perform dynamic characterization and identification of modal parameters in such complex and heterogeneous structures, in view of the starting of a process of health monitoring over time. In this talk, three of the most widespread techniques for the analysis of the ambient vibration response will be outlined, that is: peak picking, singular value decomposition and stochastic subspace identification. Moreover, the results of the analysis of the ambient vibration recordings of the response of the Colosseum, Basilica of Maxentius, Trajan Column, together with a nineteenth century railway bridge will be presented. The experimental modal characteristics, that is natural frequencies and mode shapes, of these structures are compared to the results of finite element modal analysis. An updating of the finite element model to fit the experimental data is also tried. In the case of the Colosseum, the updating benefited from wave propagation tests providing information on the mechanical parameters of the blocks. The application of such kind of tests is illustrated in a broader perspective of detecting the presence of inner defects.

Bio

Annamaria Pau is assistant professor of Solid and Structural Mechanics at the Department of Structural and Geotechnical Engineering of Sapienza University of Rome since 2008, where she has taught courses of Statics and Structural Mechanics on the undergraduate curriculum in Architecture. She graduated in Civil Engineering from the University of Cagliari in 1999 and earned her PhD in Structural Engineering from Sapienza University in 2004. Her research interests set out from structural identification, damage detection and characterization of undamaged and damaged structures based on the observation of their dynamic response, also covering experimental investigations. In recent years, the structural complexity encountered in real cases brought her to investigate the description provided by micropolar continua, the effect of the state of stress on the dynamic response and the opportunities provided by sonic and ultrasonic stress waves in structural monitoring and damage imaging.