



INNOVATIVE BRIDGE DESIGN HANDBOOK

Construction, Rehabilitation
and Maintenance

Edited by
Alessio Pipinato



Innovative Bridge Design Handbook

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Dedication

To Laura, Francesca, Annamaria and Francesco

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Martin B.T.

Modjeski and Masters, United States of America

Barney T. Martin received his undergraduate degree in civil engineering in 1974 from Louisiana State University, Baton Rouge, Louisiana, and his master's and PhD degrees from Tulane University in New Orleans, Louisiana, in 1981 and 1992, respectively. Dr. Martin is active on the Transportation Research Board, having recently served as chairman of the Concrete Bridge Committee and the Steel Bridge Committee. He has had extensive highway bridge design experience, having been the managing engineer on bridge design projects ranging from simple girder spans to projects involving major suspension bridges. He has significant experience in the evaluation and design of long-span bridges, particularly the inspection and evaluation of parallel wire main cables of suspension bridges. In addition, he has significant experience in the design, structural evaluation, load rating, repair, and construction support of bridges of all types, both fixed and movable. President and CEO of Modjeski and Masters.

Middleton C.R.

Cambridge University, United Kingdom

Campbell Middleton is the Laing O'Rourke Professor of Construction Engineering and director of the Laing O'Rourke Centre for Construction Engineering and Technology at Cambridge University, Cambridge, UK. He joined the staff at Cambridge in 1989, having previously worked for nearly 10 years in bridge and highway construction and design in Australia and with Arup in London. He is chairman of the UK Bridge Owners Forum, established in 2000 by representatives of the major bridge-owning organizations in the UK to identify research needs and priorities for bridge infrastructure. He has been awarded the Diploma of the Henry Adams Award of the Institution of Structural Engineers twice (in 1999 and 2014) and the Telford Premium Award (1999) and Telford Gold Medal (2010) from the Institution of Civil Engineers. He was elected a fellow of the Transport Research Foundation in 2005, has been involved in the development of bridge codes of practice, and acts as a specialist bridge consultant to clients in the UK and abroad.

De Miranda M.

Studio de Miranda Associati, Technical Director, Italy

Mario de Miranda obtained his civil engineering degree from the Politecnico di Milano, Italy, in 1979. His work, experience, and research are mainly related to the design and

construction of cable stayed and suspension bridges, wind engineering, and the history of construction. He is a partner of Studio de Miranda Associati—Consulting Engineers and has experience in the design and construction of bridges and structures. He has been involved with many major projects, most of these as lead designer, including large cable stayed bridges in Italy, the Dominican Republic, Brazil, Algeria, and India, as well as with the construction engineering of the Storebaelt suspension bridge in Denmark. He has given lectures on bridge design and construction in many countries and is the author of 60 papers and chapters of books on the same subject. Since 2006, he has been an Invited Professor at the University IUAV of Venice, where he teaches structural design and steel construction.

Modeer V.

AECOM, United States of America

Victor is a Senior Geotechnical Program Manager for AECOM in St. Louis, Missouri. He has 38 years of geotechnical experience mainly in the US, but also in Europe and the Middle East. He is a PE and has been awarded certification by the ASCE as a Diplomate in Geotechnical Engineering (D.GE). He has a Master of Science Degree with emphasis in geotechnical engineering from Purdue University and a Bachelor of Science in Civil Engineering from Louisiana State University. He is a US Navy Civil Engineer Corps veteran. Victor served as a Committee Chairman for the Transportation Research Board Committee on Earthworks and served on the Bridge Foundation committee. He served as Co-Chairman of the Illinois Joint Research and Technology Center. He has managed geotechnical foundation investigation, design and construction projects for cable stayed, long span deep girder and truss bridges. He has also designed cofferdams for bridge foundation construction including evaluation of support for a floating cofferdam system in the Mississippi River. Victor has performed seismic analyses of new and existing bridge foundations for effects from liquefaction and lateral loads. He has published peer reviewed papers including “Foundation Selection and Construction Performance - Clark Bridge Replacement” that is cable stayed.

Nowak A.

Auburn University, United States of America

Andrzej Nowak is a professor of structural engineering and chair of the Samuel Ginn College of Engineering at Auburn University, in Auburn, Alabama. In addition, he is vice-chair of the Transportation Research Board-Task Group for LTBP Bridge Traffic and Truck Weight and a member of two American Concrete Institute (ACI) committees: the ACI 343 Committee on Concrete Bridges and ACI 348 Committee on Concrete Bridges. He is the author of more than 100 papers in renowned scientific journals. His research interests include the analysis and design of structures; code calibration procedures for load and resistance factor design (LRFD); the ultimate, serviceability, and fatigue limit states; load models for bridges, including extreme events and their combinations; resistance models for materials and structural components; evaluation of existing structure diagnostics, field testing, and proof loading for bridges; weigh-in-motion procedures for bridges; and mechanical properties and design criteria for lightweight concrete structures.

Patton R.

Norfolk Southern Railway Corporation, United States of America

Ronald D. Patton is a Division Engineer at Norfolk Southern Railway and has over 39 years of engineering experience involving the maintenance, construction and design of railway bridges and other structures. He is currently Chairman of American Railway Engineering and Maintenance of Way Association Committee 10 and a member of ASCE.

Pipinato A.

AP&P, Italy

Alessio Pipinato obtained a bachelor's degree in building and structural engineering from the University of Padua, and a bachelor's degree in architecture from the University of Venice-IUAV. He earned his PhD at the University of Trento in structural design. He served as an adjunct professor, teaching university courses in bridge engineering and structural design, and has been a research collaborator at the University of Padua for more than ten years in the structural engineering sector (ICAR09-08B3). His twelve years of engineering career encompasses founding his own engineering consulting firm, AP&P, serving as the CEO, scientific and technical director; and providing bridge, structural engineering, research and development (R&D) services. He is/has been a member of the American Society of Civil Engineers (ASCE), Structural Engineering Institute (SEI), International Association for Bridge and Structural Engineering (IABSE), Associazione Italiana Calcestruzzo Armato e Precompresso (AICAP), International Association of Railway Operations Research (IAROR), Collegio Tecnici dell'Acciaio (CTA), International Association for Life Cycle Civil Engineering (IALCCE), International Association for Bridge Maintenance and Safety (IABMAS), Collegio Ingegneri Ferroviari Italiani (CIFI), European Convention for Constructional Steelwork (ECCS), and American Institute of Architects (AIA). He is also the author of more than 200 scientific and technical papers on structures and bridges, the chair of international conference sessions (including IABMAS 2010, Philadelphia; and IABMAS 2012, Milan). In addition, he is peer revisor of many international structural engineering journals, including the *ASCE Journal of Bridge Engineering*, *Engineering Structures*, *Structure and Infrastructure Engineering*, *International Journal of Fatigue*, and *Journal of Structural Engineering*. He has participated in a number of international research projects. His research interests includes the design, analysis, and assessment of bridges; structural analysis and design; fatigue and fracture of steel bridges; reliability analysis; life cycle assessment; probabilistic analysis; design of innovative structure and application of new materials in structures; construction control design, and fast bridge construction. He has won many international and national awards during his professional and academic career, and he served as a volunteer in the evaluation of structures during seismic emergencies for the National Service of the Civil Protection (L'Aquila 2009, Emilia Romagna 2012).

Reiner S.

Leonhardt, Andrä, und Partner, Germany

Saul Reiner was born at Lünen, Westphalia, Germany in 1938 and graduated as Dipl.-Ing. in structural engineering from the Technical University of Hannover in 1963. He

started his career with steel contractor Hein Lehmann AG Düsseldorf. In 1968, he went to Leonhardt, Andrä, und Partner, where he was appointed managing director in 1992. After his retirement in 2003, he became a consultant. From 1993 to 2006, he was licensed as a Legally Authorized Checking Engineer in Germany. In 1994, he was appointed a lecturer on steel bridges at the University of Stuttgart; in 2003, he received an honorary doctorate in structural engineering from the Technical University Carolo-Wilhelmina Braunschweig. In 2005, he became an honorary member of the Argentine Society for Structural Engineering (AIE). During his professional career, he has been involved in the design, site direction, or checking of about 40 cable stayed and suspension bridges and numerous other bridges, mainly with steel or steel composite girders. He is the author of numerous papers, mainly on steel, steel composite, and cable stayed bridges and related problems like cables and protection against ship impact.

Rosignoli M.

Dr. Ing., PE, United States of America

Marco Rosignoli has 32 years of experience in the design and construction engineering of complex bridges, the industrialization of large-scale bridge projects, and the design review and forensic engineering of bridge construction machines. Working with bridge contractors, designers, and owners in 21 countries on four continents, he has served as designer, reviewer, or technical leader for the construction of five cable stayed bridges, nine incrementally launched bridges, multiple balanced-cantilever bridges, and well over 50 km of light-rail and high-speed railway bridges. An international authority on mechanized bridge construction, he is the author of four books published worldwide, four book chapters, and over 80 publications and presentations, and he holds 32 patents on bridge construction methods.

Schanack F.

Austral University, Chile

Frank Schanack studied civil engineering at TU-Dresden, Germany, in 2003, and received his doctorate at Universidad Cantabria in Spain in 2008. Since then, he has been a professor on bridges and structures at Universidad Austral de Chile, where he is currently the director of the Institute of Civil Engineering. His research has an integrated focus on all aspects of bridge engineering, including conceptual design, analysis details and erection methods, and inspection and maintenance. He has worked as a consultant for the design, construction, and maintenance of over 100 bridge projects in Germany, Spain, Argentina, and Chile.

Schultz A.E.

University of Minnesota, United States of America

Arturo Ernest Schultz is a structural engineering researcher and educator. He holds a bachelor's degree in civil engineering from Southern Methodist University in Dallas, Texas, as well as master's and doctoral degrees in civil engineering from the University of Illinois at Urbana-Champaign. He is a fellow of The Masonry Society (TMS)

and member of the Precast/Prestressed Concrete Institute (PCI), the American Concrete Institute (ACI), and the American Society of Civil Engineers (ASCE). He is past recipient of the John B. Scalzi Award (TMS), the C.T. Grimm Award (Canada Masonry Design Centre), and the Charles C. Zollman and Martin P. Korn awards (PCI).

Stewart L.

Georgia Institute of Technology, United States of America

Dr. Lauren K. Stewart, a renowned expert in blast research, came to the School of Civil and Environmental Engineering (CEE), in Atlanta, Georgia, from the University of California, San Diego (UCSD). She earned her bachelor's and doctoral degrees in structural engineering from UCSD, where she was a postdoctoral scholar and lecturer. She is also a National Defense Science and Engineering Graduate Fellow and holds a P.E. license. She has been involved with many blast and earthquake experimental projects, including the blast testing of steel structural columns, steel stud wall systems, and high performance concrete (HPC) panels using the UCSD blast simulator. She has also conducted advanced finite element analysis for the World Trade Center 7, AFRL Munitions Directorate small munitions program, and programs supported by the Technical Support Working Group. She is considered by many to be among the top blast researchers in the US, and has served as a senior blast engineering consultant to a number of organizations since 2007.

Ferretti Torricelli L.

SPEA Ingegneria Europea, Italy

Lucio Torricelli received the master degree in civil structural engineering at the Politecnico di Milano in 1991. In 1992 he joined the design office of the construction company of Italstrade S.p.a. focusing on prestressed concrete bridges realized with various construction methods (frontal launching, movable scaffolding, balanced cantilever). Then expanded the field of expertise with the involvement as senior engineer and team leader, in the design of other transportation infrastructures, such as tunnels, and underground stations. In early 2000, joined the company SPEA Ingegneria Europea, engineering company partner of Autostrade per l'Italia-Atlantia Group, focusing the interest on highway infrastructures, as senior bridge engineer. He has been leading structural engineer charged of the design of some of the major bridges structures of the "Variante di Valico" project (A1 Highway); other noticeable works includes the preparation of the conceptual guidelines for "widening and seismic retrofitting of existing structures of A14, A9 and A1 highways"; participated in the implementation of the new structural Eurocodes, with special reference to packages 2, 3 and 4, developing a set of comparative studies in order to best fit the new design requirements; team member of the "Gronda di Genova" project, in charge of the structural design of the new Genova cable stayed viaduct; since July 2011 is the Head of Structural Engineering Department of SPEA Ingegneria Europea.

Vardanega P.J.*University of Bristol, United Kingdom*

Paul J. Vardanega studied at the Queensland University of Technology in Brisbane, Australia, and earned a bachelor's degree in engineering with First Class Honours and a University Medal and a Master of Engineering Science in 2007 and 2008, respectively. He is a member of Engineers Australia and a member of the American Society of Civil Engineers (ASCE). He holds a PhD from Cambridge University in geotechnical engineering, completed under the supervision of Professor Malcolm Bolton, Fellow of the Royal Academy of Engineering (FREng). From April 2012 to September 2013, he worked as a research associate at the Laing O'Rourke Centre for Construction Engineering and Technology at Cambridge (under the direction of Professor Campbell Middleton, FICE) working on the project: "Best Practice Guide for Structural Monitoring over the Whole Life of Assets,". In September 2013, he took up the position of lecturer on civil engineering at the University of Bristol.

Webb G.T.*Parsons Brinckerhoff, United Kingdom*

G.T. Webb recently completed his PhD on structural health monitoring (SHM) at Cambridge University, UK. His research focused on ways in which data can be interpreted to provide useful information, an area in which surprisingly little work has yet been published. He has developed a new classification system to aid users of SHM systems to clearly understand how data is used and what information can realistically be obtained. These new findings will help to better target investments in SHM so that results with a genuine impact can be delivered. Now working for Parsons Brinckerhoff in London, he is part of a team developing a long-term SHM strategy for the Hammersmith Flyover in London. Findings from his research are being used to ensure that a useful and beneficial system is delivered.

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Foreword

I acknowledge all the special men and women I have met during my life. Special people believe in the young, believe in their dreams, and cultivate their good intentions and their small and big ambitions; special people are not selfish, believe in the next, helps and not leave others with indifference. Special people work in a transparent and fair way, believe in a better future, and do the best to change it during their lives. Special people truly believe in science, research, and the culture, and do their work seriously, not for personal gain. Special people want to live intensely this great opportunity that is life, and does it with the other, spreading positivity, courage, respect, selflessness, integrity, and honesty. Let's do that every day, and the world will be better!

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Preface

Bridges represent the top level of the intellectual capacity of the construction sector and the structural engineering field: new materials, new construction innovations, and a wide variety of studies are focused in the sector that is very near the boundary of other innovative engineering and scientific field (aerospace, materials engineering etc.). Moreover, an increasing demand for new and retrofitted infrastructure is taking place worldwide, so the interest in the bridge engineering field is remarkable from both an economic and a political point of view.

This book is the culmination of much long and hard work, which began four years ago, when I realized that a comprehensive work on the state of the art of bridges, including theory, design, construction, research and development (R&D) innovation was not present in the worldwide panorama. I haven't found any existing manuals with useful content on the market, as these usually include a lot of content without precise answers on the most crucial questions arising from the everyday experience in the theory and practice of bridge engineering and design. Instead, I realized I wanted to create an innovative handbook, a reference book that could be updated regularly in the pursuit of innovation. First, I have tried to make a monograph on the matter on my own, spending some years to research books and articles during my doctoral and post-doctoral studies on bridge engineering. Second, I realized that a lot of colleagues among academics and prominent engineers from all over had the same thoughts and trusted in the proposal to write an innovative monograph on bridge engineering and design—not a manual, but a reference book in which students, academics, and engineers could find useful information on topics arising both from the studies, but also from the practice and from research works. The preparation work of this book has been very intensive, with thousands of communications passing between me and the other authors.

I hope that this final work has successfully expressed our thoughts and goals.

All the chapters in this book have been “built”—I love that term, which highlights the fatigue and the hard time spent by contributors preparing every chapter—and presented by leaders in the specific area of expertise in question, engineers or academics who have made a very deep and appropriate preparation in their arguments. So if you are searching for the best design and research tool in this area, here you can find everything you need to know about bridge design, engineering, construction, and R&D.

Why do I consider this not to be a conventional book? All the chapters have been realized with the specific mood of going over the present and the past knowledge including the best, most forward-looking information we have on. We have tried to look into the future as well, and for this reason, this book is quite different from the traditional literature on the matter. Most of the chapters includes R&D information

on the specific issue, which describe research and innovations, or where research is going and what the market is asking for. Sometimes the two aspects coincide, but other times not at all.

I have personally chosen every contributor, trying at the same time to have in the same study the most prominent authority in the fields and representative authors from all over, in order to prepare a leading, innovative book.

I want to acknowledge all the authors and their collaborators, more than 100 persons from all over the world, who have worked to create what is now a real, innovative handbook.

Note

The views and opinions expressed in the following chapters are those of the authors and not necessarily reflect those of the organizations they belong to or of Elsevier. The reader is cautioned that independent professional judgment must be exercised when information set forth in this handbook is applied. Anyone using this information assumes all liability arising from such actions.