Preface

Masonry constructions are the majority of the buildings in Europe's historic centers and the most important monuments in its architectural heritage. Given the age of much of these constructions, the demand for safety assessments and restoration projects is pressing and constant. Nevertheless, there is a lack of a widely accepted approach to studying the statics of masonry structures. Simple linear elastic models, which form the foundation of common structural analyses, cannot in fact be applied to masonry, because of its inherent, widely differing response to tension and compression.

The ingenious Heyman no-tension model well interprets the masonry behavior and is widely used and was fruitfully applied in analyzing the statics of systems of arches. However, completely different assumptions are commonly used for other types of masonry structures in other contexts, for example, strength evaluations of masonry buildings under seismic forces, which is rather perplexing, given that a masonry arch, a vault, and a building wall are all still made of the same material. Moreover, most masonry studies approach strength evaluations of structures through Limit Analysis, forgoing any study of the construction's actual state.

This book aims to fill these gaps in the study of masonry structures by formulating a new, comprehensive, unified theory of statics of masonry constructions extending the Heyman model to the analysis of the masonry continuum. The book features complete mathematical derivation of all the given results and, through an interdisciplinary approach combining engineering, architecture, and a bit of history, advances from the simple to the complex, while striving, above all, for clarity.

The book is the result of 30 years of research and professional experience. It is divided into nine chapters, each of which begins with historical notes and an introduction highlighting the main aspects of the topics covered.

The strength and deformability of masonry materials are addressed in the first chapter. The second chapter deals with the deformation and equilibrium of masonry solids. The kinematics of strains and crackings, as well as internal stress states are analyzed. The fundamental concepts of admissible equilibrium and the parameters governing collapse strength are examined in detail to highlight the strict relation

between structural geometry and strength. The notion of minimum thrust is then introduced—an aspect of masonry structural behavior that extends the field of application of Limit Analysis to include the study of the actual stress states of masonry constructions. The third and fourth chapters examine the static behavior of the main basic masonry structures, such as arches and vaults.

By way of example, static analyses are conducted on a number of renowned examples from the world's architectural heritage, such as ancient Mycenaean domes, the Roman Pantheon, the large cross vaults of the Baths of Diocletian, and the domes of Santa Maria del Fiore in Florence and Saint Peter's in Rome. The fifth chapter turns to a detailed analysis of the statics of the Roman Colosseum and examines the reasons for its actual state of damage. The sixth chapter describes and analyzes the statics of cantilevered stairways, a typical element whose structural behavior is still somewhat unknown. Chapter seven then takes up the structural analysis of walls, piers, and towers under vertical loads. The stability of such structures is heavily affected by the nonlinear interactions between the destabilizing effects of the axial loads and masonry's no-tension response. The instability of towers, leaning towers in particular, is addressed in a specific section of the chapter. In this regard, a detailed stability analysis was conducted at the famous Leaning Tower of Pisa, which has recently undergone a successful restoration work. The eighth chapter then analyzes the statics of Gothic cathedrals, with particular reference to analysis of their resistance to wind actions. The 1294 collapse of the Beauvais cathedral is also examined in-depth. The last chapter deals with the seismic behavior of historic masonry buildings and crucial issues regarding their conservation. The latter part of the chapter regards, in particular, the analysis of the transmission of seismic forces between the various constituents of a building, together with the out-of-plane and in-plane strengths evaluations of multi-story walls with openings.

The book is addressed especially to researchers, engineers, and architects operating in the field of masonry structures and of their consolidation and restoration, as well as to students of civil engineering and architecture. It is, for the most part, an English translation of a recent Italian book of mine "Statica delle Costruzioni Storiche in muratura." The English edition has, however, been revamped to address some new questions and, hopefully, improve on the original.

Many thanks go to colleagues Michel Frémond and Franco Maceri for their precious encouragement to prepare the book. Many thanks also go to Anthony Cafazzo, English Lecturer at the University of Pisa, who insightfully and patiently assisted me in revising the text.

I would also like to thank all the graduate and postdoctoral students, researchers, visiting scholars, external collaborators, and students, who attended my courses at the Faculty of Engineering at the University of Rome Tor Vergata—all of whose contributions have been duly noted—for their invaluable assistance in the various research studies without which this book would not have been possible.

Rome Mario Como
January 2012

Preface to the Second Edition

The interest accomplished in the first edition together with the need to improve the text with new developments, widening, and revisions, due to the recent research achievements on the subject matter, is the motivation of this second edition of the book.

A new section has been added to the first chapter, analyzing new test results for masonry strength under inclined compression with respect to the joint direction; this is a subject of great importance for the evaluation of the seismic strength of masonry walls. Within the second chapter, dedicated to the Fundamentals of Statics of Masonry Structures, a new Limit Analysis of elastic no-tension one-dimensional systems has been included; this is a very useful tool, for instance, in the strength analysis of masonry walls reinforced with steel ties. The third, fourth, fifth, and eighth chapters are substantially unchanged, except for some additions concerning the construction of the Brunelleschi Dome in Florence and the inclusion of a new section dealing with the thrust evaluation of round cross vaults, then applied to the vaults of the Diocletian Baths in Rome. In the sixth chapter the study of the effect of the inclined cracking on the buttresses and leaning towers static behaviors has been included. This study has been very useful for the analysis concerning the strength assessment of Gothic Cathedrals under side wind, a topic which has been revised and developed within the seventh chapter. The ninth chapter, dealing with the seismic analysis of masonry buildings—a topic in which the current research has produced new remarkable results—has received the most important revisions and widening.

All these developments have been obtained thanks to the precious teamwork with Simona Coccia and Fabio Di Carlo of the Department of Civil Engineering and Computer Science at the University of Tor Vergata in Rome. To them, I address my grateful thanks.

Reflections and ideas on the topic were also triggered from the fruitful discussions that I had with the students of the Doctorate course in "Restoration of Historic and Contemporary Buildings," held at the D.I.C.A.T.A. of the University of Brescia. Also, to all these students my thanks are directed.

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Mario Como

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