Preface to the Third Edition

This new edition of this book has been driven by the numerous recent developments of the research in the field, which it was necessary to recall in the text; the work of this new version allowed the revision of the writing with the correction of many misprints occurred during the proofreading of the previous edition.

The new edition also has offered the opportunity to include, scattered in the various chapters, many refinements and improvements of the discussed topics, some of them here listed as follows: the collapse induced by the crushing of masonry in elements that cannot get deformed through mechanisms, as for instance in the platband arch; the mechanics of collapse of masonry structures with elasto-perfectly plastic reinforcements; dome statics, particularly examined in depth regarding the dome of Brunelleschi in Florence.

Furthermore, the last chapter—the 11th—regarding the behavior of masonry buildings under seismic actions, has been completely modified and integrated. The starting point of this chapter has been the consideration that masonry constructions behave very differently from ductile structures.

There is no dissipation of energy during their deformation, even if accompanied by cracks. If properly reinforced, to avoid early local failures, masonry constructions have the sole resource to escape the seismic action exhibiting *rocking* without failure, under alternate seismic action.

In this context, on the wake of the more recent research on the matter, the rocking of pier walls, which are the main resistant components of the masonry structure, has been thoroughly examined. It has been defined the dynamical overturning failure acceleration, larger than the acceleration producing the statical collapse, that is the incipient rocking. A new and proper definition of the so-called *reduced strength factor* $q$, well known in earthquake engineering, has been thus given in this chapter. This ratio, here defined as the *acceleration ratio*, rather low in value, is more appropriate to characterize masonry structures behavior, than those inherent to other formulations, which improperly go back to criteria concerning ductility of reinforced concrete or steel constructions.
Due to the actual low values of this reduced strength factor $q$, the seismic protection of historic masonry constructions requires design criteria where strength, and not ductility, has to be dominant. A focal point is thus the analysis of the chain of transmission of the seismic forces along the resistant structure of masonry buildings, together with the out of plane and in-plane strength evaluation of masonry walls, developed here with new elaborations and inclusions.

As for the previous editions of this book, all the above developments have been obtained with the cooperation of the precious teamwork with Simona Coccia and Fabio Di Carlo of the Department of Civil Engineering and Computer Science of the University of Tor Vergata in Rome. To them, I address my grateful thanks.

Reflections and ideas on the topic also triggered from the fruitful discussions that I had with the students that I have met during some doctorate courses held by myself at various Departments of Civil Engineering, as those of the University of Brescia, of the University of Parma and Naples. Also to all these students, my thanks are directed.

Rome, Italy

Mario Como

December 2016
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 this 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 for 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, the fourth, the fifth, and the 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 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.

Rome

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Mario Como
Preface to the First Edition

Masonry constructions are the great 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 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 are 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 help 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. This 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.

This book is the result of thirty 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, is 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 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 analysis is conducted of a number of renowned examples from the world’s architecture heritage, such as ancient Mycenaean domes, the Rome 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 Rome 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 is conducted of 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 multistory walls with openings.

This 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 this book. Many thanks go also 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 of 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.

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