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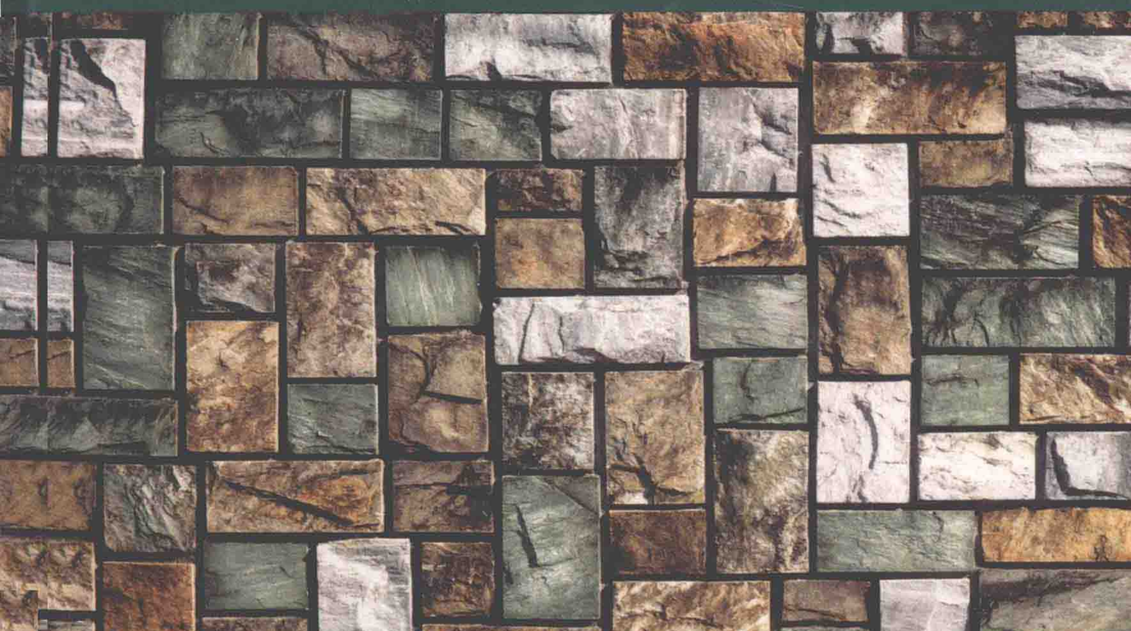
Sustainable Masonry

Stability and Behavior of Structures

Thierry Ciblac and Jean-Claude Morel



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Preface

This book is the result of the meeting of two complementary approaches to the same subject: masonry. The first is the approach developed by Thierry Ciblac at the *Ecole Nationale Supérieure d'Architecture de Paris la Villette* (National School of Architecture of Paris La Villette), which revisits historical design methods using digital tools. The second consists of studies led by Jean-Claude Morel at the *Ecole Nationale des Travaux Publics de l'Etat* (National Civil Engineering School), which are based on experiments with masonry structures of earth materials. The convergence of these two approaches occurs through the common use of the theory of yield design.

This book was written to promote understanding of the mechanical stability of masonry structures in a contemporary context and to introduce it to the readers. This approach will allow contractors to carry out diagnostics on existing heritage and to design new structures.

The challenges presented by sustainability criteria have provided – or restored – respectability to masonry constructions using earth materials. The latest research in this area has been formalized by putting it into perspective with historical approaches. This is done with the dual purpose of making design methods used for old structures (mostly from the eighteenth century) more accessible and providing "simple" tools for understanding their behavior. In particular, developments relative to graphic statics, take on new educational and demonstrative values with the use of digital tools.

We wish to thank Noël Challamel for proposing the idea for this book, for his detailed proof-reading of the manuscript and for his valuable advice.

Such a book is the fruit of a collective effort. Experimental work, in particular, is the result of a team effort where students, contractors, technicians, engineers and researchers cooperate.

Work on dry stone began in 1998 at ENTPE, instigated by Patrick Cohen in the Luberon Regional Natural Park.

Work on earth began in 1981 at ENTPE, instigated by Myriam Olivier and later, Ali Mesbah. These two researchers were eager to share their knowledge, and J.C. Morel benefitted from their expertise upon arrival at ENTPE. Note that Claude Boutin encouraged J.C. Morel to study the theory of yield design in order to apply it to earth materials.

The authors are particularly thankful to a number of PhD students, whose work has enriched this book. Laboratories and funding involved in these PhDs are specified as following:

– Abalo P'kla (DGCB, *Ecole Nationale des Travaux Publics de l'Etat* – National Civil Engineering School);

– Boris Villemus (DGCB, *Ministère de l'Ecologie, du Développement Durable et de l'Energie-MEDDE* – Ministry of Ecology, Sustainable Development and Energy);

– Givanildo Azeredo (DGCB, *Conselho Nacional de Desenvolvimento Científico e Tecnológico CNPQ-Brésil* – National Council for Scientific and Technological Development CNPQ-Brazil);

– Anne-Sophie Colas (DGCB, *Ministère de l'Ecologie, du Développement Durable et de l'Energie-MEDDE* – Ministry of Ecology, Sustainable Development and Energy);

– Quoc Bao Bui (*Centre National de la Recherche Scientifique-CNRS* - National Centre for Scientific Research);

– Apostolia Th. Oikonomopoulou, (*ARIAM-LAREA, Ministère de la Culture et de la Communication* – Ministry of Culture and Communication);

– Hong Hanh Le (LGCB, *Ecole Nationale des Travaux Publics de l'Etat* – National Civil Engineering School).

These PhDs were carried out with the assistance of technical staff:

– Odile Roque (MEDDE technician);

– Jean-François Halouze (MEDDE technician);

– Sébastien Courrier (MEDDE technician);

– Erwan Hamard (MEDDE technician);

– Stéphane Cointet (MEDDE technician);

– Joachim Blanc-Gonnet (CNRS research engineer).

The experimental work which forms the basis of the first part of this book was carried out in close cooperation with builders, notably via the *Ecobâtir* network, which includes Nicolas Meunier, Vincent Rigassi and Alain Marcom, experts in earthen construction. In the field of dry stone, the series of experiments were conducted by Paul Arnaud (OPUS) and Philippe Alexandre (Lithos-APARE) at Le Beaucet. The second series was conducted in Saint-Germain-de-Calberte by the *Artisans Bâtisseurs en Pierres sèches* (Dry Stone Builders' Association) led by Marc Dombre and Christian Emery. The third series was conducted at Pont de Montvert by the *Artisans Bâtisseurs en Pierres sèches*, led by Bruno Durand and Thomas Brasseur.

Denis Garnier co-supervised Anne-Sophie Colas' thesis, the second thesis on dry stone retaining walls, bringing her valuable skills to the optimum implementation of yield design.

Rabia Charef-Morel carried out careful proof-reading of the manuscript and created Figures 4.1, 4.2, 4.3, 11.1 and 11.3.

Paul McCombie, Nicolas Meunier, Bruno Durand provided the photographs in Figures 1.1 and 1.3.

Research was also done in the context of two national projects: PEDRA and RESTOR:

– RGCU PEDRA project No. 10 MGC S 017, studies on dry stone or weak mortar masonry of the Civil and Urban Engineering Network, coordinated by Eric Vincens of the *Ecole Centrale de Lyon* (Lyon Central School).

– RESTOR project, restoration of dry stone retaining structures, of the PNRCC program of the Ministry of Culture and Communication, coordinated by Eric Vincens of the *Ecole Centrale de Lyon* (Lyon Central School).

Studies on rockfill dams and dry stone masonry revetment were initiated at the instigation of EDF.

Finally, J.C. Morel was supported by the Rhône-Alpes region in furthering his studies in England, with a 5 month placement at the University of Bath.

The sections on graphic statics, principles of yield design and stability of curvilinear masonry, written by Thierry Ciblac, are directly related to his teaching and research activities at the MAP Maacc/CNRS-MCC UMR 3495 (ex. ARIAM-LAREA) laboratory at the *Ecole Nationale Supérieure d'Architecture de Paris La Villette*. The author wishes to thank Louis-Paul Untersteller and François Guéna, founders and successive directors of the laboratory, and the initiators of the research focus on digital tools to help preserve heritage masonry. The quality of their welcome, their support and their experiences as educators and researchers has been an invaluable aid. The development of graphic statics in dynamic geometry has been the subject of collaboration with the Department of Architecture of the Massachusetts Institute of Technology, under the MIT-France program, with Professor John Ochsendorf and Philippe Block, then a student, whom we also wish to thank.

Thierry CIBLAC and Jean-Claude MOREL

June 2014

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Part 1

Technologies and Construction Process

1

Introduction to Sustainable Masonry

1.1. Definitions of sustainable masonry

This book is particularly focused on masonry structures made of local materials, stone and earth. They are among the first materials to have been used by humans to build shelters thousands years ago and they are called, in this book, Earth Materials. In this context, earth masonry deals with adobe or compressed earth block, or rammed earth if the material is manufactured in successive layers.

This book does not particularly apply to baked clay brick and cement sand blocks, which are within the scope of Eurocode 6.

1.1.1. *Sustainable constructions*

Here, we consider sustainable development as defined in [BRU 87] as "a development mode that meets the needs of present generations without compromising the ability of future generations to meet their own needs".

In this book, we will only consider the mechanical stability of masonry. However, in this introductory chapter, we consider some elements of thermal and hydric behavior, socio-economic aspects, and sustainability and environmental impacts of these structures. These elements will include references so that the reader, if he wishes, can further his knowledge of all these key aspects of sustainability.

Local materials are acquired from or near the construction site. Here, 'near' means a distance of about 20 km. Local materials used in construction have an impact due to their transportation. When a material is taken from on-site, as was often the case for earth, rubble stone masonry (rubble stone blocks and earth or sand lime mortar) and dry stone constructions, the impact is obviously reduced [HAB 12].

This precision concerning the implied proximity of the word "local" is important since it implies that the production of these materials cannot be completely industrialized. Materials therefore maintain a very variable composition, depending on the soil that is available locally and the geology. Therefore, it is not possible to give a standard composition of these materials. Local materials of interest here are: cut or uncut stone assembled with (rubble stone masonry) or without (dry stone) mortar, adobe and earth mortar and finally rammed earth. These materials are "earth" materials.

1.1.2. *Masonry structures*

By masonry structures, we refer to an arrangement of blocks hand-stacked by a mason, regularly or irregularly, with or without a mortar, over successive layers. We exclude "Cuzco rampart" type masonry or blocks exceeding one ton, quarry cut and assembled with a crane and Opus Incertum in general.

This masonry is done manually, thus is greatly dependent on the mason's skill, but following specific rules, which form part of the mason's skill set. We will also consider rammed earth as a part of masonry as they depend on a mason's art, even if they do not constitute a stack of small elements but rather layers of compacted earth.

In an industrial context, "sustainable development" can be interpreted as requiring structures to be designed based on criteria, taking all environmental consequences (in the broad sense of the word) induced by these constructions into account. However, the objects discussed here are the result of a systemic approach whereby an optimum is obtained according to environmental and sustainability criteria, amongst others, which revert to being current. Vernacular architecture was erected in a context of limited resources and energy shortages, thus respecting the criteria of minimum impact on the planet. Their age provides an obviously tangible guarantee of durability. However, we must also consider the innovation that characterizes sustainable masonry, as the use of old materials in a modern context can only be achieved through an adjustment that includes innovation.