Semana de Engenharia 2010
Guimarães, 11 a 15 de Outubro

A MULTI-PHYSICS APPROACH APPLIED IN MASONRY STRUCTURES BASED IN NON-HYDRAULIC LIME

Mateus A. N. Oliveira[1], Paulo. B. Lourenço[2], Miguel Dias Azenha[3]
ISISE, Department of Civil Engineering, University of Minho
E-mail: mateusantonio@ufmg.br[1]; pbl@civil.uminho.pt[2]; miguel.azenha@civil.uminho.pt[3]

KEYWORDS
Historic buildings, masonry, lime, numerical simulation, coupled multi-physics problems

ABSTRACT

The structural safety of historic buildings with undisputable cultural, artistic and architectural value is a quite important issue and its study is frequently supported by government agencies. In Portugal, as well as Europe in general, there is a significant quantity of historic constructions comprehending binders based on non-hydraulic lime mortars (Lourenço et al. 2006)
. The non-hydraulic lime is produced from relatively pure limestone that, after placement, hardens gradually from the surface to its interior due to reaction with dioxide of carbon present in the atmosphere (reaction usually termed as carbonation). Mortar generally only represents about 15% of the volume of structural masonry (Binda 2000). Nonetheless, it has been acknowledged as the principal cause for deformations/movements. This fact justifies the necessity for a detailed structural analysis of the role of mortar within the scope of the structural behavior of masonry structures (Lourenço 1996)
Conventional structural analysis methods which only consider the mechanical behavior of the masonry's constituents are generally insufficient to describe the stress states of complex structures such as ancient buildings (Degrise et al. 2002 and Maravelaki-Kalaitzaki et al. 2003). This is because they neglect a range number of physico/chemical interactions that may be crucial for stress development and distribution. Some examples of these interactions that cause the necessity for coupled multi-physics approaches are: (i) non-uniform carbonation induces a non-uniform distribution of stiffness (Binda et al 1991 ; and Ferretti and Bažant 2006 and Maravelaki-Kalaitzaki et al 2003), which has a clear influence on stress distribution; (ii) the internal moisture state of lime influences both shrinkage and carbonation; (iii) the carbonation process results in the hardening of lime and porosity reduction, thus reducing further transport of humidity and carbon dioxide; (iv) temperature profiles affect the kinetics of carbonation, as well as moisture and carbon dioxide diffusion; (v) the structural effects of temperature that can induce important stresses, particularly in multi-leaf masonry walls in which temperature is markedly non-uniform (Elsen 2005).
This PhD project aims to establish a multi-physics approach to the numerical simulation of the structural behavior of historic buildings comprised of masonry with non-hydraulic lime, based on the finite element method. It is intended to perform a series of experiments for model validation and parameter estimation that may allow the sustained implementation of a numerical framework for thermo-hygro-carbo-mechanical (Saetta e Vitaliani 2004) analysis of ancient masonry structures. This numerical framework should help a better understanding of the stress changes that occur in this kind of structures throughout the years (and centuries), allowing better estimates of structural performance and safety to be made. Although there are several previous studies focused on the physical phenomena related to temperature (Azenha 2009; Elsen 2005 and Saetta and Vitaliani, 2004), moisture (Azenha 2009 and Elsen 2005) diffusion and carbonation in masonry with non-hydraulic lime mortars, only one research work was found in the literature, that clearly focuses on an integrated approach of carbo-hygro-mechanics . Furthermore, the cited research work was limited to numerical simulation, without any kind of experimental parameter estimation or even in-situ results validation. It is thus intended with this PhD work to contribute to this relatively unexplored approach in historic lime mortar based masonry structures.
The main tasks to be performed in this research work, which has begun approximately one year ago, are summarized in the following paragraphs.
In regard to thermal fields, an bearing in mind the advanced state of knowledge on this issue available on the ISISE research group, focus will be centered in the influence of temperature on moisture diffusion and carbonation kinetics, with the conduction of small experiments (under controlled environmental conditions) that can back the adoption of chemical activity models (most probably based on Arrhenius formulations). Small scale tests are to be performed on masonry structures, with temperature monitoring as to check the capacity of simulating temperature fields under arbitrary environmental conditions (temperature, wind, solar radiation, night cooling, evaporation with latent heat removal, etc.).
Regarding to moisture fields , the work will focus on matters that have few known contributions in the

literature, such as the effects of long-term drying/wetting cycles on the internal distribution of humidity. Particular attention will be given to the non-linear diffusion coefficients of moisture and the hysteretic behavior of the moisture isotherms of lime mortar. The moisture conditions impose deformations associated with drying shrinkage, which assume non-uniform distribution in lime , in correspondence with the progressive drying, so, the implemented models will also have to take into account the quantification of the relationship between internal water loss from the mortar matrix and the corresponding shrinkage (Cazalla 2000).

The acceleration of lime carbonation related to the increasing in the moisture content on the mortar matrix will also be experimentally investigated and its effect duly accounted in the implemented numerical models. It is also intended to study the transport coefficients of carbon dioxide and their relation to the effect of reduced porosity caused by carbonation (Ferretti and Bažant 2006)

For the mechanical model, special attention will be paid to the creep behavior of lime mortar and its consequences in stress development. Furthermore, a specific experimental campaign for continuous E-modulus of prisms will be conducted (with use of a recently developed measurement technique based on modal identification), evaluating the effect of carbonation depth on the overall stiffness of the prisms. Based on the obtained results, and by performing retro-analysis, it is expected to derive models for the relation between local stiffness and the carbonation state (Azenha 2009).

The thermal transport model, such as humidity and carbonation models, will be initially implemented using the finite difference method in 1D. However, after the development phase and validation, the model be implemented in 3D, using Finite Element Method in 3D, allowing the study of more complex situations. In regard to the mechanical model, as no new implementations are expected, the commercially available DIANA software will be used.

When the numerical framework is complete and available, its results will be compared with experimental data for validation. Such comparison is initially intended in small scale laboratory specimens. In a second phase, the implemented thermo-hygro-carbo-mechanical analysis will be applied to at least two case studies of real structures which emphasize and verify the simulation capabilities. These case studies will allow demonstrating the relevance of using multi-physics approaches in the evaluation of stress states in lime mortar based masonry structures.

REFERENCES

Azenha, M. Â. D. N. 2009. Numerical simulation of the structural behaviour of concrete since its early ages. Faculty of Engineering of the University of Porto. Doctoral Thesis.

Binda, L. ; Saisi, A. and Tiraboschi, C. 2000 . Investigation procedures for the diagnosis of historic masonries. , Construction and Building Materials. 14 p. 199– 233.

Binda, L., Anzani, A. and Gioda, G., 1991. An analysis of the time dependent behaviour of masonry walls. ", in Proc. 9th Int. Brick/Block Masonry Conf.., 2 , (DGfM, Berlin) p. 1058-1067.

Cazalla, O.; Rodriguez-Navarro, C.; Sebastian, E.; Cultrone 2000. Aging of Lime Putty: Effects on Traditional Lime Mortar Carbonation., G. J.Am. Ceram. Soc., 83, [5], p. 1070-1076 .

Degrise, P.; Elsen, J. e Waelkens, M. 2002. Study of ancient mortars from Sagalassos (Turkey) in view of their conservation. Cement and Concrete Research. 32 p. 1457–1463.

Elsen, J. 2005. Microscopy of historic mortars – a review, Cement and concrete Research, 36, p.1416-1424.

Ferretti, D. and Bažant, Z. P. 2006 Stability of ancient masonry towers: Stress redistribution due to drying, carbonation, and creep. Cement and Concrete Research 36 p.1389–1398.

Lourenço, P.B.B 1996. Computational strategies for masonry structures. Netherlands, Delft University Press .

Lourenço, P. B. ; Luso, E. e Almeida M. G. 2006. Defects and moisture problems in buildings from historical city centres: a case study in Portugal. Building and Environment Volume 41, Issue 2, February, Pages 223-234.

Maravelaki-Kalaitzaki, P. ; A.Bakolas, and Moropoulou, A. (2003). Physicochemical study of Cretan ancient mortars,. Cement and Concrete Research. 33 p. 651– 661.

Saetta A. e Vitaliani R. V. 2004. Experimental investigation and numerical modeling of carbonation process in reinforce concrete structures, Part I: Theoretical formulation, Cement and concrete Research, p. 571-579.

AUTHOR BIOGRAPHIES

Mateus Antônio Nogueira Oliveira is an Engineer (Federal Univesity of Minas Gerais, Brazil, 2008, when received the award Prof. Artur Guimarães, honor given to the best student of the year) .

Paulo J. B.B. Lorenço is a Full Professor at the Civil Engineering Departament of School of Enginneering of the University of Minho.He received his PhD at Delft University, 1996.

Miguel Dias Azenha is a Research assistant at the Civil Engineering Department of the School of Engineering of the University of Minho, Portugal. He received his PhD at University of Porto, 2009.