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Characterization of the uniaxial compression behaviour of unreinforced masonry—Sensitivity analysis based on a numerical and experimental approach

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ABSTRACT

Experimental testing of masonry is a difficult, expensive and time consuming process, involving the use of large facilities and a significant number of samples to achieve representative results. On the contrary, computer simulations are practical tools that avoid most of the previous disadvantages. However, such tools are based on experimental evidences and demand experimental results to be validated. These aspects motivated the development of strategies based on numerical models and experimental tests. However, numerical sensitivity analyses based on this approach to predict the behaviour of masonry are not easily found or developed.

The main objective of this work is to perform a sensitivity analysis by using computer simulations of laboratory tests to predict the compressive behaviour of unreinforced concrete masonry made from materials with different mechanical properties and geometrical layouts. A three dimensional micro-modelling with continuous finite elements and an elastic–plastic damage constitutive model were used to simulate the masonry behaviour. This numerical model was previously calibrated and validated through experimental data obtained from a small number of laboratory tests. The results obtained showed accuracy and a good agreement with the known aspects of the compressive behaviour of masonry, demonstrating the ability to perform numerical sensitivity analyses with few laboratory resources.

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Abbreviations:

A	loading area
d	isotropic scalar degradation variable
D_0^{el}	initial (undamaged) elastic stiffness
E	modulus of elasticity of masonry
E_0	modulus of elasticity of the masonry materials
F	compression load
f_b	normalized compressive strength for the unit
f_l	mortar flexural strength
f_K	characteristic compressive strength of masonry
f_m	average compressive strength for the mortar joints
F_{max}	maximum compression load
G	potential plastic flow
g	full width of the mortar strips
G_F	fracture energy
K	constant defined for calculation of f_K
K	cratio between the tensile and compressive stress invariants at initial yield
K_E	constant defined for calculation of E
L	distance between measurement points of Δv or Δh
$\overline{p}$	effective hydrostatic pressure
$\overline{q}$	Von Mises equivalent effective stress
R^2	coefficient of determination
t	total thickness of the wall
α, β, γ	adimensional parameters
Δh, Δv	horizontal and vertical displacements
ε	total strain
ε_c	uniaxial compressive strain
ε_{cu}	strain for σcu
ε^{el}	elastic strain
ε_{max}	strain of masonry for F_{max}
ε^{pl}	plastic strain
$\tilde{\varepsilon}^{pl}$	multi-axial equivalent plastic strain
$\tilde{\varepsilon}_c^{pl}$	compressive equivalent plastic strain
ε_t^{pl}	tensile equivalent plastic strain
ε_t	tensile strain
ν	Poisson coefficient
σ	Cauchy stress
$\overline{\sigma}$	effective stress
σ_{b0}	initial equi-biaxial compressive yield stress
σ_c	uniaxial compressive stress
$\overline{\sigma}_c$	compressive effective stress
$\overline{\sigma}_t$	tensile effective stress
σ_{c0}	initial uniaxial compressive yield stress
σ_{cu}	uniaxial compressive strength
$\ddot{\overline{\sigma}}_{max}$	maximum principal effective stress (algebraic value)
$\overline{\sigma}_t$	tensile effective stresses
σ_{to}	uniaxial tensile strength
ψ	dilation angle
ϵ	"eccentricity" parameter

1. Introduction

1.1. General aspects

The mechanical behaviour of masonry is complex and experimental characterization through laboratory testing is one of the most important tools available to researchers to understand it. However, masonry laboratory testing requires high time consuming and expensive resources, since it requires long time preparing and difficult manipulation of test samples, expensive and specific testing machines and measurement devices, and the large scatter attained on the mechanical and geometrical properties of the masonry constituents and construction procedures usually demands a significant number of test samples to achieve representative results.

In order to overcome these difficulties, simple numerical models and empirical expressions based on test data have been developed in the past to predict the masonry compressive behaviour. The complexity of masonry behaviour and the search for more general and accurate numerical models, together with the evolution of computational resources, motivated in more recent years the development of successful strategies. These strategies are based on the use of advanced modelling techniques together with experimental data obtained from simple laboratory tests made to the constituent materials used in the units and joints. However, the main focus of these studies is the validation of the numerical models. Moreover, studies focused on the prediction of masonry compressive behaviour by considering variations on the constituent materials are not easily found or sufficiently developed.

The main contribution of this work is to demonstrate the use of computer simulations to predict the compressive behaviour of masonry systems (e.g. compressive stress–strain diagrams) made with units and mortar joints with different mechanical and geometrical properties.

To that end, a masonry wall system was used as a case study, in particular a shell bedded masonry system made with lightweight concrete hollow units and lightweight mortar joints. This system was developed in the scope of a national research project in Portugal to be used in single leaf walls with improved thermal performance and enough structural resistance. More details about the development and characterization of this masonry system can be found elsewhere [1–3].

The sensitivity analysis was performed through numerical simulations of laboratory tests on masonry samples according European standard EN 1052-1 [4], by using three-dimensional micro-modelling associated to an elastic–plastic damage constitutive model. Perfect bond conditions between the units and the joints interfaces were considered to facilitate the process of numerical convergence, since difficulties arise when a discontinuous approach and frictional models were used to simulate these interfaces.

The mechanical properties required by the constitutive model were determined from a small number of laboratory tests performed on the units and mortar samples, and from available literature. In the particular case of the units, the calibration of the constitutive model was performed not only