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A detailed micro-modelling approach for the structural analysis of masonry assemblages

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ABSTRACT

Over the last 50 years, a significant amount of effort has been taken to develop numerical approaches and tools for the structural analysis of masonry. These range from considering masonry as an anisotropic continuum (macro-models) to the more detailed ones considering masonry as an assemblage of units and joints (micro-models). In this paper, a detailed micro-modelling approach for the analysis of masonry couplets and prisms is proposed. The approach represents masonry units and mortar joints as an assemblage of densely packed discrete irregular deformable particles bonded together by zero thickness interface laws. The mechanical properties (here referred to as micro-properties) of irregular particles and contacts are responsible for the mechanical behaviour of masonry. In addition, the approach allows failure to occur either at the brick, mortar and/or brick/mortar interface. A series of computational models were developed and their results are compared against small-scale experimental findings. A good agreement between the experimental and the numerical results was obtained which demonstrates the huge potential of the modelling approach proposed. The significant advantage of this approach is to model cracking as a real discontinuity among particles and not as a modification in the material properties. In addition, reliable prediction of masonry strength can allow one to reduce the costly and timely experimental testing and avoid the reliance on conservative empirical formulas.

1. Introduction

Masonry is a heterogeneous anisotropic material, which is composed of units (e.g. bricks, stones, blocks, etc.), bonded together with or without mortar. It is probably the oldest building material that is commonly used today. Although masonry is easy to construct, its mechanical behaviour is non-linear and thus complex to understand. Movements in masonry may arise due to the application of external load, foundation settlement, temperature and moisture variations. Such movements could lead to several different defects in serviceability state such as cracking and ultimate limit state such as crushing and spalling [9]. In masonry, cracking can occur: (a) at the masonry units; (b) at the mortar; (c) at the brick/mortar interface; and (d) in all of the above. Cracks in masonry may not open uniformly but may close and open according to the type of stresses applied to them over time. Cracking in masonry reduces its load carrying capacity and could lead, eventually, to collapse of the structure.

The need to predict the in-service behaviour and load carrying capacity of masonry has led researchers to develop several computational strategies and tools that are characterized by different levels of complexity. These range from the classical plastic solution methods [8] to the most advanced non-linear computational formulations (e.g. finite element and discrete element methods of analysis). The selection of the most appropriate method to use depends on, among other factors, the structure under analysis; the level of accuracy and simplicity desired; the knowledge of the input properties in the model and the experimental data available; the amount of financial resources; time requirements and the experience of the modeller [18]. Also, it should be expected that different methods should lead to different results depending on the adequacy of the approach and the information available. Preferably, the approach selected to model masonry should provide the desired information in a reliable manner within an acceptable degree of accuracy and with least cost.

For a numerical model to adequately represent the behaviour of a real structure, both the constitutive model and the input material properties must be selected carefully by the modeller to take into account the variation of masonry properties and the range of stress state types that exist in masonry structures [31]. It is also impor-

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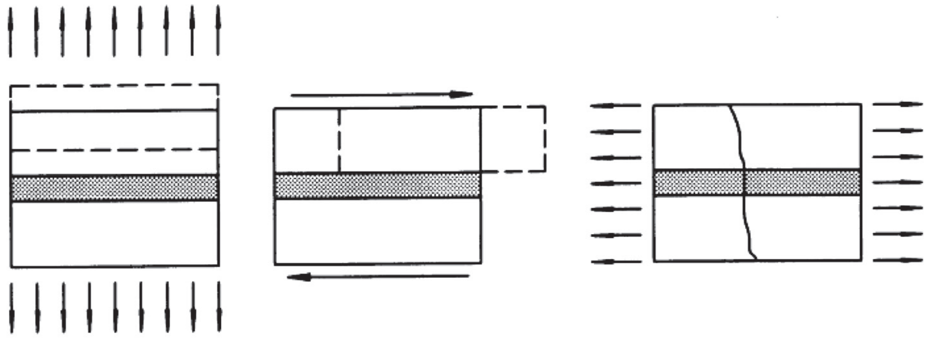
Nomenclature

Abbreviation

A_c	contact area
σ	stress
σ_n	normal stress
K_n	nodal stiffness
M_n	nodal mass
$\dot{u}$	velocity
x_i	node coordinates
τ_{fr}	residual strength
τ_u	ultimate shear strength
ΔF^n	normal force increment
ΔF^s	shear force increment
Δt_n	limiting time-step
ΔUn	normal contact displacement increment
ΔUs	shear contact displacement increment
Δt	time step
Deg	degrees
E	modulus of elasticity
f_t	tensile strength
Jcoh	joint cohesion
Jdil	joint dilation angle
Jfric	joint friction angle
Jfric_res	residual joint friction angle
JKn	joint normal stiffness
JKs	joint shear stiffness
Jten	joint tensile strength
OPC	Ordinary Portland Cement
T	tension
TT	tensile test
u	deformation
Un	normal contact displacement
Us	shear contact displacement
v	Poisson coefficient
τ_{max}	maximum shear stress
τ_{res}	residual shear strength
τ_s	shear stress
τ_u	ultimate shear stress
$F(t)$	total nodal force
frac	user-defined time-step reduction factor
m	mass
t	time

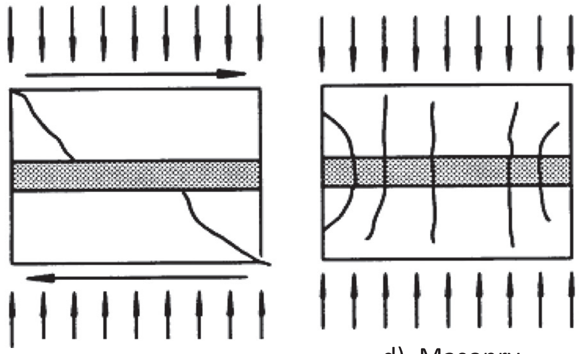
tant that the numerical model is able to capture the failure mechanisms which can occur in masonry. Fig. 1 shows five basic failure mechanisms: (a) and (b) are mortar joint mechanisms, (d) is a masonry unit mechanism and (c), (e) are combined mechanisms involving cracking in both units and mortar. However, variation in the stress-state within masonry can lead to combined failure



a) Joint tensile cracking

b) Joint slip

c) Cracking of unit in direct tension



e) Unit diagonal tension crack

d) Masonry crushing

Fig. 1. Masonry failure mechanisms [16].

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