MODELLING OF DEFORMATION AND DAMAGE OF HETEROGENEOUS-ENGINEERING STRUCTURES: MASONRY MECHANICS

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1. Introduction

Sustainability of the built-up environment requires making best use of historical and monumental constructions of the architectural heritage and of many bridges of transport systems made of masonry and designed according to empirical rules. The conservation and restoration of these masonry structures has to be supported by an exhaustive structural assessment. An awareness of the limitations of the conservative approximations commonly made in structural analysis, generally providing underestimations of the load-bearing capacity of these structures, has stimulated grat interest in new approaches to the mechanical modelling of masonry structures.

Compared to conventional steel and reinforced concrete constructions, where the structure can be clearly identified, masonry constructions are very complex structural systems obtained from an assemblage of different components like walls, vaults and pillars, requiring highly statically indeterminate structural models. Moreover, masonry is a heterogeneous material consisting of units, such as bricks, blocks, ashlars, adobes, irregular stones etc. assembled with mortar or dry joints according to different patterns. As a consequence a great variety of masonry materials can be found ranging from periodic brick masonry to dry stone rubble masonry.

The mechanical response of this two-phase composite material observed in experiments is rather complex, depending on the unit and joint material, the masonry pattern and the applied loads. Moreover, experiments on units and masonry assemblages show uncertainty on the material characteristics. This behaviour can be attributed to the quasi-brittle behaviour of the components and the interfaces. Elastic, damage/crack and stress induced anisotropy, including different response to tensile versus compressive stress, hysteretic response to cyclic loads and fracture are the main observed phenomena, having a strong effect on the stress redistribution in structural components (walls and vaults) and on dynamic response to seismic actions. As a consequence modelling of deformation and damage of masonry material and structures aimed at prediction of the behaviour of masonry structures under ultimate loads, base settlements and seismic events remains a challenge.

2. Constitutive models for damaging brick/block masonry

As usual in modelling material, different approaches to the analysis of masonry structures such as pillars, walls and vaults, can be pursued in order to simulate the main features of the mechanical response. In any case, the structural model has to encompass several constitutive ingredients such as elasticity, plasticity, unilateral contact, friction-damage, localization and size effects, fracture and time dependent response. In discrete approaches the constituents are modelled individually and the actual assemblage of brick/block masonry is considered in detail. Although these models may be useful in interpreting experimental results and in the calibration of material parameters, they lead to excessive computational effort even for simple structures, thereby making continuous models more appealing for applications to large scale structures.

Apart from the case of the so-called no-tension material proposed by Heyman to formulate a theory for the limit analysis of masonry structures, the complexity of the masonry material makes the formulation of purely phenomenological models a rather difficult task, with the exception of the case of rubble or disordered masonry. On the other hand, mesomechanical approaches based on the homogenization of a periodic cell, a representative element of brickwork, are suitable for regular brick/block masonry, frequently found in ancient and historical constructions, where the units are joined by horizontal and vertical mortar beds to obtain a periodic structure. This latter approach is interesting because it may allow consideration of different characteristic lengths in the structural system (materials, unit cell, structure).

The evaluation of the load carrying capacity of eccentrically compressed pillars, commonly based on the simplifying assumption of homogeneous material, is analyzed considering a periodic discrete model of the stack of units. In this class of problems, defined at the scale of masonry units, the mismatch of the material parameters may significantly affect the inelastic mechanisms at the lateral free edges of the pillar and at the head mortar joints and the overall strength. Theoretical evaluations of the load carrying capacity are compared to experimental results and open issues are discussed. Application to the assessment of masonry bridges are presented and discussed.

Modelling the in-plane and out-of-plane response of perforated masonry walls is a critical issue in the evaluation of the seismic vulnerability of masonry buildings. This problem is analyzed considering constitutive models at different details of description of the masonry pattern and of the inelastic frictional-damage mechanisms. Starting from the simplified assumption of a layered continuum with horizontal critical planes, where damage mechanisms are attained, the analysis encompasses more elaborate constitutive models based on the homogenization of periodic masonry cell, including micropolar and higher order constitutive equations, whose characteristic lengths are related to the unit size and to the bond pattern. Simulations of experiments on perforated masonry walls are presented. The consequences of assuming different constitutive models including friction/plastic and damage ingredients are analyzed in terms of structural response and computational implementation and comparisons with results provided by simple models (elastic-no-tensile-resistant for instance) are drawn.

6. References

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