Stochastic Micro-modelling of Historic Masonry

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ABSTRACT

The non-linear structural analysis of historic masonry structures is sometimes difficult to perform due to the highly irregular geometric features, the inherent variability within the materials, as well as the limited amount of experimental data available. The state-of-art review encompassed within the work focuses on current methodologies for analyzing the strength of masonry structures and the viability of stochastic analysis along with the utilization of random fields. The present work details a specific methodology, subsequent application, and a presentation and discussion of the results for the overall compressive strength of the masonry walls of St. Ann's Church in Czech Republic. A multi-scale 2D finite element modelling approach was adopted. Based on the statistical analysis of the walls, in a mesoscale-level representation of masonry, small stones were grouped in with the mortar and treated as a matrix component with homogenized properties, while large stones were treated as discrete inhomogeneities. To characterize this matrix component, microscale-level models were used, in which only the small stones and mortar were represented as inhomogeneity and matrix phases, respectively. These models were built using test-windows placed in randomly generated, statistically equivalent microstructure morphologies. By simulating uniaxial compression and tension tests, statistical distributions for compressive and tensile strength, stiffness, and fracture energy were determined. On the mesoscale-level, overall stiffness and compressive strength were determined by simulating uniaxial compression tests on models considering only the large stones embedded in the homogenized matrix. An initial calculation was run with uniform properties for the matrix using mean values obtained from the micro-scale models. Secondly, random fields were utilized to describe the matrix properties to account for the inherent variability and inhomogeneity of the matrix. Furthermore, the multi-scale study was performed for two different threshold sizes defining the "small" stones to compare differences. Based on the analyses completed for the meso-scale models with uniform matrix, the average compressive strength was calculated to be 0.95-0.9 MPa, with the lower bound values coming from models with decreased projected stone area. Overall, the compressive strength decreased from the mortar to micro-scale to mesoscale-levels due to high stress concentrations in the mortar/matrix material caused by the irregular topology of the stones. The models where matrix variability was represented with random fields exhibited similar failure mechanisms but with strengths 5-6% lower than the models with a uniform matrix, therefore the effect of the spatial variability of the matrix properties was considered insignificant. Lastly, qualitative methods were utilized to validate the results to be used in equivalent continuum-based modelling and further analysis of St. Ann's Church.