Construction and Building Materials 140 (2017) 129–138

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Spatial variability and sensitivity analysis on the compressive strength of hollow concrete block masonry wallettes

Fei Zhu [a], Qiang Zhou [a], Fenglai Wang [a,b,c,*], Xu Yang [a]

[a] School of Civil Engineering, Harbin Institute of Technology, Harbin 150090, China
[b] Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, Harbin Institute of Technology, Harbin 150090, China
[c] Key Lab Smart Prevention and Mitigation of Civil Engineering Disasters of the Ministry of Industry and Information Technology, Harbin Institute of Technology, Harbin 150090, China

HIGHLIGHTS

- A stochastic micromechanical FE model for concrete masonry is proposed and verified.
- Monte Carlo simulation with a Latin hypercube sampling technique is employed.
- The effect of spatial variability for material parameters is investigated.
- A global sensitivity analysis is studied to evaluate the material parameters effects.

ARTICLE INFO

Article history:
Received 7 October 2016
Received in revised form 27 January 2017
Accepted 19 February 2017
Available online 1 March 2017

Keywords:
Probabilistic analysis
Hollow concrete block
Material uncertainties
Spatial variability
Global sensitivity analysis
Sobol' method

ABSTRACT

This probabilistic study investigates the effect of material uncertainties on the numerical analysis of masonry wallette axial compressive strength. Detailed micro-modeling techniques are adopted to model hollow concrete block masonry by separately describing the specific equations for material constituents (blocks and mortar) and block-mortar interfaces. A Latin hypercube sampling technique is used to generate random input variables from the empirical distribution functions of the material parameters. A quasi-static nonlinear analysis is then carried out using a Monte Carlo simulation to evaluate the effect of the spatial variability of material parameters on the compressive behavior of masonry wallettes. The results show that ignoring the spatial variability of material properties may cause a model to overestimate the probability of compression failure. Additionally, the independent and cooperative effects of the material parameters on masonry compressive strength are investigated using first order, second order, and total sensitivity indices. The numerical results indicate that block tensile strength influences masonry compressive strength the most. Several parameters for masonry compressive strength are also ranked in order of importance.

1. Introduction

The use of masonry structures is still widespread throughout the world. This is because it is an easily available material and its construction is rapid and economical. Hollow concrete blocks have replaced traditional clay bricks in recent construction because of the advantages of higher bearing capacity, farmland protection, and energy conservation [1]. In most practical applications, masonry structures are primarily stressed in compression [2]. Therefore, one of the most important and challenging problems is to assess the compressive strength of masonry walls. In the past, extensive experiments have been carried out on the compressive strength of masonry prisms and wallettes [3–6]. However, because of the diversity and complexity of masonry material, laboratory testing becomes expensive in terms of time and cost. In order to overcome these difficulties, the finite element (FE) technique has gained popularity.

Several numerical analyses have been performed during the last two decades on the compressive behavior of masonry prisms and wallettes for various purposes. Linear and nonlinear FE models have been developed to study the compression strength and failure mechanisms of masonry prisms and wallettes [7–12]. The effect of various parameters, such as block and mortar strength, mortar bedding, height-to-thickness ratio, type of hollow-block geometry, bonding arrangement, and core alignment, on compressive

* Corresponding author at: School of Civil Engineering, Harbin Institute of Technology, Room 521, Haihe Road #202, Nangang District, Harbin, Heilongjiang Province 150090, China.

E-mail address: fl-wang@hit.edu.cn (F. Wang).

http://dx.doi.org/10.1016/j.conbuildmat.2017.02.099
0950-0618/

strength in masonry prisms and wallettes has been investigated. However, most previous studies on compression behavior have been conducted using deterministic FE models. That is to say, material uncertainty was not taken into consideration when simulating compressive performance. In reality, the mechanical properties of the masonry component (concrete block and mortar) are often scattered over a wide range [13]. This may lead to a deterministic numerical analysis that over- or under-estimates the composite material properties because the input material parameters have a large effect on the prediction accuracy of an FE model. Thus, a probabilistic analysis approach is necessary to overcome the limitations of a deterministic approach by randomly sampling the values of the input parameters.

Moreover, some of these input parameters may have a significant influence on the compression strength, while others may have little influence. Therefore, it is necessary to evaluate the degree of influence of these parameters on the simulation results. Sensitivity analysis is an effective technique for evaluating the relative contributions of the input factors that can be divided into two groups: local sensitivity analysis and global sensitivity analysis [14]. In contrast to local sensitivity analysis, global sensitivity analysis examines the impact of the factors over their entire spatial range, and it can account for both individual variables and their interaction sensitivity indices. In general, the Sobol' method [15], a variance-based sensitivity analysis, is widely adopted for global sensitivity analysis.

The aim of this paper is to perform a probabilistic analysis of the compression strength of masonry wallettes considering the uncertainty of the material parameters. Using a micro-mechanical FE model and applying Monte Carlo stochastic analysis, the influence of spatial variability and sensitivity of each material parameter in the nonlinear response of masonry wallettes were studied. The remainder of this paper is structured as follows: Section 2 describes the methodology of the probabilistic analysis, Section 3 briefly describes the experimental test, and Section 4 presents the details of the numerical models. The stochastic analyses of non-spatial and spatial models are compared in Section 5 together with a discussion of the sensitivity indices of the input parameters. Finally, the conclusions are provided in Section 6.

2. Methodology

In this study, the methodology adopted for the probabilistic analysis of the compression strength of masonry wallettes is illustrated in Fig. 1. Considering the uncertainty of material properties, a probabilistic micromechanical FE model was generated using ABAQUS FE software [16] to simulate the heterogeneous behavior of masonry wallettes. The statistical distribution and variability of each property of the materials are determined in accordance with the experimental results presented in Section 3. In step 1 of Fig. 1, Latin hypercube sampling (LHS) is used in MATLAB [17] to sample the material parameters. I n step 2, stochastic analysis is carried out by using Monte Carlo simulation. In step 3, the influences of the spatial variability of material properties on the wallettes' performance are experimentally validated in terms of compressive strength and stress-strain curves. In step 4, a global sensitivity analysis based on the Sobol' method is also performed to quantify the sensitivity indices of the input random variables. The parametric FE models were programmed in MATLAB and the numerical results are extracted using Python programs; thus, the system can automatically repeat the computation of a probabilistic analysis without any human intervention.

2.1. Latin hypercube sampling

Although Monte Carlo simulation is a powerful technique for processing and estimating a stochastic structural response, it is computationally expensive because of the large number of samples needed to draw statistically meaningful results. In order to reduce the computational time, LHS was used in constrained Monte Carlo sampling scheme in this work. This method is a stratified sampling approach that allows efficient estimation of the statistical characteristics of random fields.

In essence, the idea of LHS is to divide the cumulative distribution function of each random variable into N equiprobable intervals and then randomly select one value from each interval. For k random variables, the process is continued until a set of $N \times k$ samples is obtained, which is created using random sample combinations of different variables. The i-th row values in the matrix are the Latin hypercube sample for the i-th Monte Carlo run. This strategy avoids repeating samples that have been evaluated. Meanwhile, it forces the tails of a distribution to participate in the sampling process and accelerates the convergence of the calculations if the output is sensitive to those tails.

2.2. Sobol' method

The Sobol' method is a global sensitivity analysis approach that is based on variance decomposition [15]. Nonlinear and

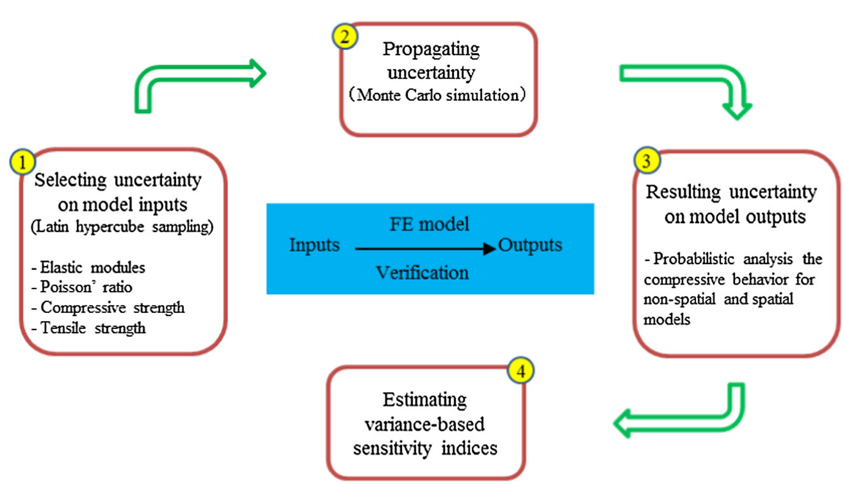

Fig. 1. Flowchart of the probabilistic analysis of compressive strength. In this method, a Latin hypercube sampling (LHS) technique is employed (step 1) with Monte Carlo simulation (step 2). The influence of spatial variability (step 3) and sensitivity (step 4) of each material parameter in the masonry wallettes nonlinear response are determined.