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In-plane numerical analysis of a double-layered ashlar wall

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ABSTRACT

In this study, experimental and numerical analysis results of double-layered stone walls were compared. The numerical model was modeled in the Abaqus program, and the modeling stages were given in detail. As a result of the study, the analysis of the model was carried out and it was observed that it corresponded with the experimental data near perfectly.

Introduction

Masonry structures constitute an important part of today's building stock. Since some of these structures have the status of historical buildings, their preservation and restoration are of great importance. For this reason, many researchers around the world carry out experimental and numerical studies in order to determine the behavior of masonry structures and to evaluate possible situations and take precautions. In this study, modeling, and analysis of the in-plane behavior of a layer of hollow double-layered cut stone walls, designed to be used in new modern stone buildings with monumental value, using the finite element method has been carried out.

In recent years, the use of numerical tools and the development of these tools have become quite common in examining the structural behavior of masonry structures. Thanks to these developments, especially considering the irregularity of masonry structures and the uncertainty of the parameters, numerical analysis has gained superiority over analytical analysis and has become most preferred. In some instances, it is even proposed as an alternative to physical experiments. The main idea here is: If a model can simulate the structural behavior of a masonry structure, that means it can predict the structural response of the building to anticipated loads while assessing the building's safety [1].

Today, there are more than one type of numerical methods. The finite element method (FEM), discrete element method (DEM), limit analysis and applied element method (AEM) are the first to come to mind. The choice of these methods depends entirely on the person solving the problem and how this problem will be solved. Different models used to solve problems may give different results, so no model can be called the most precise model [2]. For instance, according to [3], the most appropriate model depends in particular on the structure analyzed, the data used and the experience and skills of the analyst. Oliveira (2003) defines the most appropriate model as the one that provides the desired result at the lowest cost, within an acceptable error, and most importantly, reliably [4].

In this study, the numerical model of the single-layered stone wall was calibrated using the experimental data of the double-layered ashlar wall designed by [5] in his PhD thesis. In this context, the numerical analysis of the model of the single-layer and micro-sized sample, in which only lime mortar is used, was carried out using the Finite Element Method (FEM) and its in-plane behavior was examined. Within the scope of the numerical study, firstly, brief information about the finite element method is given and the stages of the formation of the numerical model are explained. Then, the in-plane behavior of the wall was compared with the experimental data after numerical analysis.

Material and Method

The Finite Element Method (FEM) in Engineering was originally developed for the analysis of problems in structural mechanics based on physical foundations. However, it was later discovered that this technique could also be successfully applied to solving problems in other classes [6]. Thus, this method has been used even in very complex problems such as the analysis of masonry structures, and with the development of computers, the use of this technique in this field has become more common. However, it has been stated that the use of the Finite Element Method in the analysis of masonry structures depends on the accepted fundamental relations, the continuity of the walls that determine the analysis subject, and an appropriate discretization [4].

The main purpose of numerical modeling is the design and analysis of the most accurate mathematical model to represent the real structure. Therefore, first of all, it is extremely important to create a model that will exhibit the behavior of the real structure [7]. In this study, within the scope of numerical analysis a simplified micro-modeling approach was preferred in the three-dimensional model. In the model, the stones are designed as a continuous element and their mechanical properties are defined with data obtained from experimental studies [5]. The 2 mm mortar used on the wall was not designed physically, but instead, discontinuous, and dimensionless elements were defined and used which is known as surface-based cohesive zone in the literature. The elastic and plastic behavior of the mortar is included in the model with the help of these discontinuous and dimensionless elements that connect the stones. Thus, the elastic and plastic behaviors of the joints of the hollow multi-layer natural stone walls are considered in the model.

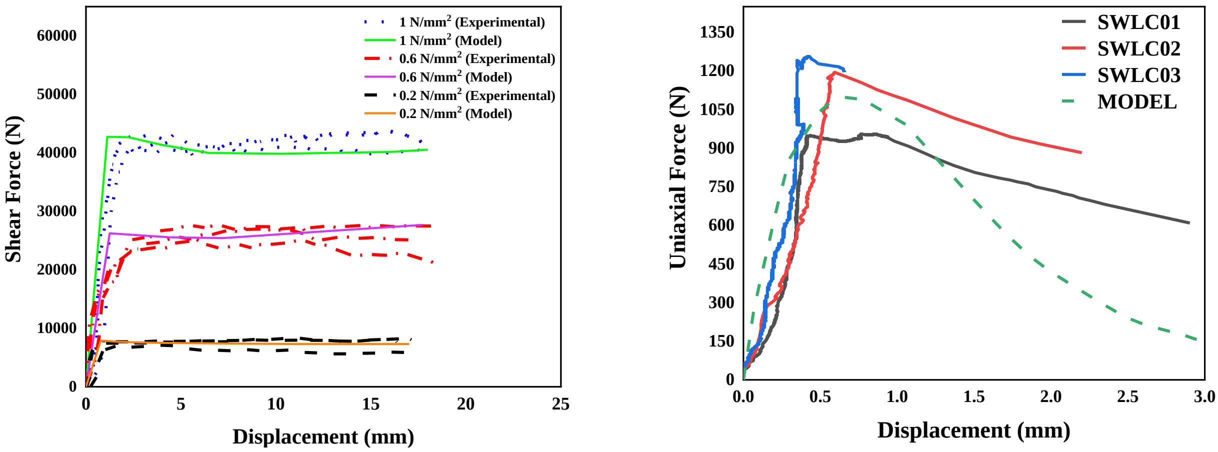
Numerical Modeling of Stone Walls

In this study, SWLIS and SWLC specimens, which are micro-sized samples, were modeled in the Abaqus program and numerically analyzed. In the analysis, the initial shear strength and compressive strength of the specimens were determined using the finite element method and compared with the experimental results [5]. For both initial and comprehensive analysis the modeling process was as follows.

- In the first stage, the design of the individual elements used in the wall specimens was carried out. In this context, two individual elements, 100 x 100 x 100 and 100 x 200 x 100 mm in size, are defined as element type C3D8R. This element type, available in the Abaqus package program, is a continuous (continuum), three-dimensional (3D), 8-node element with reduced integration points.
- In the second step, the mechanical properties of the stone are defined. For this, first the elastic behavior of the stone and then the plastic behavior were determined using experimental and literature data. The elastic behavior of the stone was determined by entering the modulus of elasticity obtained from the experimental studies and the poisson ratio. Plastic behavior is defined with the CDP (Concrete Damaged Plasticity) model.
- In the 3rd stage, the model used in the analysis was formed from the combination of the individual elements produced in the 1st stage.
- In step 4, steps are defined that impose actions on the model as load or displacement control so that numerical analysis can be performed. In both cases, actions were imposed gradually. The general non-linear static procedure, which follows the Newton-Raphson algorithm, which recalculates the balance at each increment, is adopted in the model, considering the large displacements and non-linear effects of the geometry. In addition, the damage compensator parameter, which precisely simulates the fracture in the wall joints, is used to eliminate the numerical instability caused by the reduction of stiffness in the joints. This parameter is known as viscous regularity and is taken as 0.002.
- In step 5, a surface-based cohesive interface is defined for the mortar used between individual stone blocks. Four parameters are used in the definition of this interface. First, the tangential behavior parameter is the friction formulation penalty in this parameter, and the friction coefficient was determined as 0.65 using the data obtained from the experimental studies. Latter; is the normal behavior parameter. In normal behavior, rigid contact behavior, that is, contact between adjacent surfaces of wall units, is defined by the pressure-overclosure relationship. The reason for this is the mutual pressure applications during the contact of the individual stone units in the wall. In addition, when hard contact is selected, the penetration of the individual units and the transfer of tensile stresses are also prevented. The third parameter is cohesive behavior. Within the scope of this parameter, K_{nn}, K_{ss} and K_{tt} are defined. The fourth and last parameter is the initiation and development of the crack (damage). The initiation of the crack was defined by the shear strength of the wall sample obtained from the experimental data, and the development of the crack was defined by the fracture energy.
- Finally, the support condition for compressive and initial shear models were defined similar to experimental study and the finite elements suitable for the designed sample are divided. For this purpose, the individual elements are divided into 10 x 10 x 10 mm and the numerical model was analyzed and the results were compared with the experimental studies.

Results

The vertical load-displacement curve obtained as a result of the numerical analysis was compared with the curves obtained in the experimental studies which is given in Fig. 1. As shown in Fig. 1 the correlation of the experimental result with numeric analysis show that the model designed for numeric analysis is acceptable for evaluations. As a result of the numerical analyzes, it was seen that the results of the model overlapped with the experimental results.



(a) Initial shear force – Displacement diagram (b) Uniaxial load – displacement diagram

Figure 1. Comparison of numerical analysis curve with experimental data

Conclusion

This study is a part of Doctoral Thesis (ZIA).

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Author contributions:

Ahmad Javid ZIA: Conceptualization, Visualization, Investigation, Methodology, Software**,** Data curation, Writing-Original draft preparation, Validation. **Abdulkerim İLGÜN:** Writing-Reviewing and Editing.

Conflicts of interest:

The authors declare no conflicts of interest.

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