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Strength of masonry subjected to in-plane loading: A contribution

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A B S T R A C T

The present paper discusses the strength of unreinforced masonry subjected to in-plane loading. Applying the methods of the theory of plasticity, the state of stresses under investigation and compatible failure mechanisms are discussed and an extension (new regime) to an existing failure criterion for in-plane loaded masonry without tensile strength is given. This new regime takes into account slip failure along the head joints line which could be observed in compression tests and which could compromise the safety of the design based on the existing criterion. In addition, a novel proposal for the simplified variation of uniaxial masonry strength as a function of the angle of inclination of the principal compressive stress relative to the head joints direction is derived and proposed for practical applications. Further, the present paper gives an overview of an experimental program comprising the author's own compression tests on wall elements made of concrete and calcium-silicate blocks as well as of clay brick masonry that was carried out at ETH Zurich. The results of these tests, together with those from further tests carried out by other researchers, have been used for the verification of the abovementioned proposal for the simplified variation of uniaxial masonry strength. A satisfactory agreement between the proposed simplification and test data has been found.

1. Introduction

Usually, masonry walls are primarily subjected to in-plane forces, e.g. combined gravitational and horizontal (wind and/or seismic) loads. Furthermore, due to its composite structure and inherent weak directions (along the head and bed joints) unreinforced masonry behaves in a highly anisotropic manner. This emphasizes the importance of knowing reliably the parameters of masonry strength.

A substantial amount of theoretical work has been invested in the modelling of structural masonry. Simple models are based on the linear theory of elasticity and its application to structural masonry. Regarding the serviceability limit state, i.e. when investigating the behaviour of masonry subjected to load levels up to 40–50% of the ultimate load, the applicability of the linear theory of elasticity is beyond dispute. However, when approaching higher load levels and failure nonlinear modelling is generally required. Hereby, both geometrical and material nonlinearities must be taken into account. Material nonlinearity is covered by the choice of an appropriate material model: general elastic–plastic or rigid-perfectly plastic material behaviour is usually assumed. This choice is of the utmost importance for the modelling process. In general, three different approaches, i.e. types of models, are found in the literature: micro, meso and macro models, whereas the former two are mostly applied for finite element method (FEM) analysis. In micro modelling, masonry units and mortar joints are represented by continuum elements, whereas the masonry unit-mortar interface is represented by discontinuous elements. In meso modelling masonry units are represented by continuum elements whilst the mortar joints and masonry unit-mortar interface are lumped into discontinuous elements. Finally, in macro modelling masonry is treated as a continuum, i.e. represented as one material with smeared material properties. In any case, a considerable number of material (strength) parameters are needed as input for a meaningful analysis. These parameters are not always available or not easy to determine, and this could present a big drawback for the analysis of structural masonry, especially for the application of FEM.

An elegant way of modelling structural masonry (within the framework of the theory of plasticity) is the application of the theorems of limit analysis. In spite of the inherent lack of ductility of masonry, astonishingly good results can be achieved, see e.g. Mojsilović and Marti (1997).

Regardless of the mechanical model applied, in order to gain a deeper insight into the behaviour of structural masonry and due to its very complex modelling a verification of the findings from either theoretical or numerical studies is usually obtained from experiments. Furthermore, keeping in mind the composite structure of masonry and its anisotropic behaviour it is essential to perform full-scale tests.

In conclusion, the mechanical modelling of structural masonry is rather complex and challenging but is of the utmost importance

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