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Assessment of the in-plane shear capacity of masonry panels by elementary mechanical models

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ABSTRACT

The present paper revisits the classical problem of a masonry panel clamped at its base and subject to an assigned set of in-plane loads at its upper base. The simple model presented herein seems to be able to provide some useful information on various issues involved is assessing such structures. To this end, two simple, straightforward working hypotheses are assumed: the masonry is represented as a rigid-plastic material for which the Galileo-Rankine yield criterion is adopted.

By virtue of their simplicity the adopted assumptions enable applying the static and kinematic theorems of limit analysis to obtain explicit expressions for the lower and upper bounds for the horizontal load collapse multiplier. These expressions lead to some considerations regarding the influence of the main geometric and mechanical parameters on the load bearing capacity of the panels. The main theoretical result consists of estimating the range to which the actual value of the ultimate horizontal load belongs as a function of the panel's slenderness and the masonry's strength. Comparisons between the present model's predictions and the experimental test results available in the literature on panels of very different slenderness and material makeup exhibit more than satisfactory agreement.

1. Introduction

Masonry wall panels are perhaps the most common and widely used structural elements in masonry constructions. This humble, yet fundamental component is found in nearly every masonry structure built throughout the centuries since the most ancient times and almost wholly defines the structural behaviour of masonry buildings.

Determining the load bearing capacity and mechanical response of masonry walls is a complex issue with wide-ranging implications. Panels differ in type, materials, size and shape of their components (usually stone or brick units), bonds, degree of uniformity, number of leaves and effectiveness of the connections between them. Being able to properly assess the resources that a masonry panel can mobilize before collapse is a major, all but simple, issue, which needs to be addressed for any well-reasoned investigation of the static and dynamic response of the entire masonry construction.

Since the early 1970s a large number of scientific papers, generally published with a good deal of regularity, is available in the literature regarding the mechanical response of in-plane loaded panels. Various contributions serve to illustrate the results of experiments conducted either in laboratories or directly on actual masonry constructions (amongst which, by way of example, see [16], or [14], and propose interpretative schemes of the experimentally observed failure modes [39,26]. In more recent years, this body of knowledge has formed the bases for many technical standards (for example, Italian and European codes), which in their current versions provide the safety criteria to be used for panels subject to horizontal actions, in addition to vertical loads.

Perusal of the literature devoted to this subject highlights the large number and wide variety of mechanical models used in an attempt to predict what the structural behaviour of a masonry panel might be. In simplified schemes, the whole panel is seen as a single one-dimensional or two-dimensional structural element (for a comparison between some of these models see [32], while more detailed analyses, mostly numerical, aim to evaluate the displacement and stress fields affecting such structures. By way of example, see Pelà et al. [34] or, more recently, Baraldi and Cecchi [4]. Moreover, further variants correspond to different constitutive relations and failure criteria that may be chosen to represent the behaviour of the panels' constituent material (considered as a homogeneous body) or, alternatively, of its different building materials (when the simultaneous presence of stone elements, or bricks, and binder is instead explicitly taken into account). Such a diversified panorama has accordingly been accompanied by the adoption of a variety of failure criteria, often relying on semi-empirical relations, even at the regulatory level. A detailed critical analysis of the set of criteria corresponding to different failure modes can be found in Calderini et al. [11].

The wide range of mechanical models on masonry panels currently available in the literature clearly highlights the tangible results achieved by the research carried out in recent decades. In this regard, it is worth recalling that the development of mechanical models for masonry panels has allowed for the structural analysis of complex systems

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Nomenclature

Symbols and notations

e	vertical load eccentricity measured from the panel axis
$e_r = (\lambda - \lambda_m)/\lambda$	relative error
$f_b, f_m, K, \alpha, \beta$	symbols appearing in expression (3.1) of Eurocode 6
h, b	panel height and width
$\mathbf{i}, \mathbf{j}, \mathbf{k}$	triad of orthogonal unit vectors
$\mathbf{n}$	unit vector
P	resultant of vertical loads
$p(s)$	vertical component of the distributed load per unit length of the upper base
v_B, v_P	velocity of points B and P
α, d	inclination angle and distance from the panel upper base
α_0	inclination of the separating line between reactive and non-reactive regions within the panel
δ	d/b
$\dot{\varepsilon}_p, \beta$	rate of increase in plastic deformations, angle between $\dot{\varepsilon}_p$ and the limit domain boundary
$\zeta = \sigma_t b/P$	dimensionless tensile strength
$\eta = h/b$	slenderness of the panel
$\dot{\theta}$	angular speed
λ	horizontal to vertical load ratio (horizontal load multiplier)
λ_c	kinematically admissible value of the collapse load multiplier
λ_s	statically admissible value of the collapse load multiplier
$\lambda_m = (\lambda_s + \lambda_c)/2$	mean theoretical value of the collapse load multiplier
$\rho = P/b\sigma_c$	dimensionless load parameter
σ	stress normal component
σ_1, σ_2	principal stresses
σ_c, σ_t	masonry compressive and tensile strength
$\psi = e/b$	dimensionless load eccentricity

such as masonry walls, buildings, cathedrals, etc. subject to seismic actions [27,21,22,7]. At the same time, however, the many, often substantial differences that can be found between the different schematizations suggest that the actual resistant mechanisms of masonry walls have not yet been fully understood.

In this paper, our attention will be focused on simplified structural models for determining the mechanical response and loading capacity of rectangular masonry panels subjected to loads acting in the panel's mid-plane. It is well known that, despite the associated all-but-negligible uncertainties, from an operational point of view, current models allow for obtaining acceptable results. However, careful scrutiny of the most widespread schemes casts some doubts on the consistency of the logical processes followed. Moreover, semi-empirical relations sometimes accompany relations deduced on the basis of the initial hypotheses.

In the following, we aim to describe an evaluation process for determining the load-bearing capacity of masonry panels subject to both horizontal and vertical actions. It should be stressed that the proposed mechanical scheme is not intended to replace those already available in the literature. The much more limited goal is rather to show how a structural model intentionally kept as simple as possible and that requires knowing only few easily determinable parameters (the masonry strength and the panel overall geometrical dimensions) may be able to provide some useful indications for assessing the load-bearing capacity of masonry panels. The present contribution is set within the framework of limit analysis as applied to masonry constructions. This, by now well-established approach dates back to the fundamental contribution by Heyman [19], since which limit analysis has been applied to a very

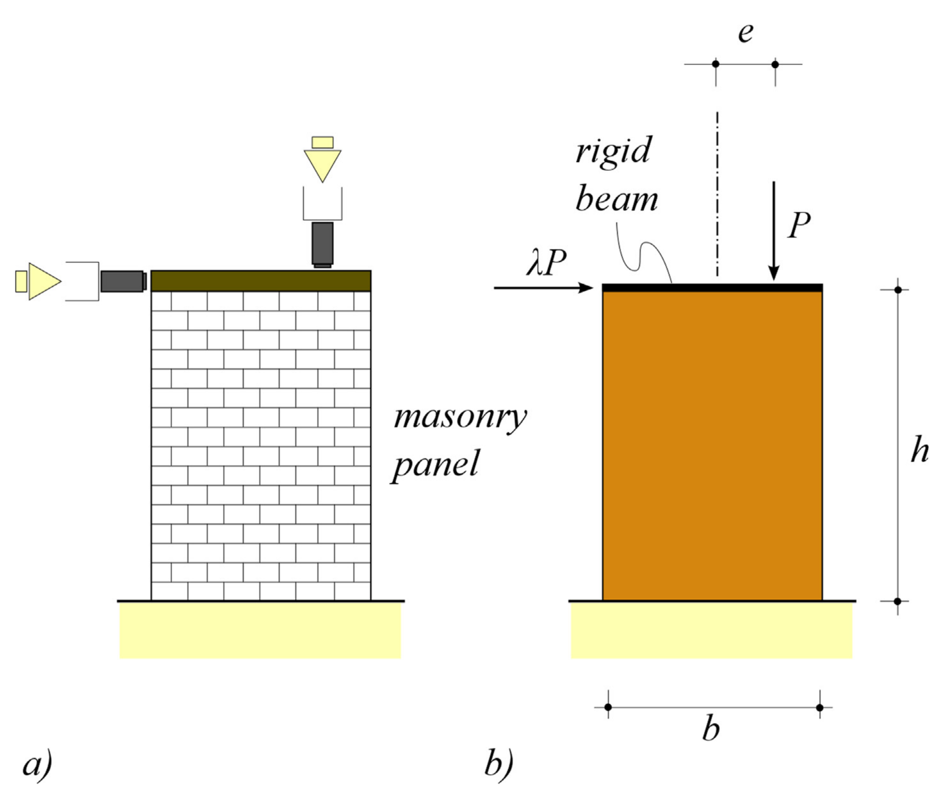

Fig. 1. The masonry panel under in-plane horizontal and vertical loads (a); the mechanical scheme (b).