Available online at www.sciencedirect.com
SCIENCE DIRECT®

Engineering Structures 27 (2005) 909–919

ENGINEERING STRUCTURES

www.elsevier.com/locate/engstruct

Application of the arc-length method for the stability analysis of solid unreinforced masonry walls under lateral loads

Mu Lu, Arturo E. Schultz*, Henryk K. Stolarski

Department of Civil Engineering, University of Minnesota, Minneapolis, MN 55455, USA

Received 17 December 2002; received in revised form 8 October 2004; accepted 30 November 2004
Available online 9 April 2005

Abstract

The stability behavior of slender unreinforced masonry members (URM) under out-of-plane lateral loads in proportion to the axial load is investigated, using a finite element model developed previously [Lu M, Schultz AE, Stolarski HK. Analysis of the influence of tensile strength on the stability of eccentrically compressed slender unreinforced masonry walls under lateral loads. Journal of Structural Engineering (ASCE) 2004;130(6):921–33]. However, significant changes are made to the solution procedure, the most important of which is application of the arc-length method. A very slender wall with a height–thickness ratio of 30 is used as an example for systematic analysis. The influence of tensile strength and slenderness parameter on the buckling capacity is also investigated. It is found that tensile strength, though very low, may produce peculiar phenomena in the post-buckling equilibrium paths. Lateral loads are shown to have a similar effect on the buckling behavior to vertical load eccentricity.
© 2005 Elsevier Ltd. All rights reserved.

Keywords: Unreinforced masonry; Out-of-plane stability; Force–moment interaction; Slenderness ratio

1. Introduction

Masonry is probably the oldest building material that still finds wide use in contemporary building industries. Its history as a building material can be traced to the earliest days of civilization. Material availability, ease of construction and relatively high compressive strength, plus other desirable characteristics, such as aesthetics, economy, durability, low maintenance, versatility, sound absorption, and fire protection, have made masonry one of the most popular building materials ever used in human history.

Despite its long use in civil engineering history, some aspects of the mechanics of masonry are still not fully understood due to its heterogeneity and nonlinear material behavior. The complexities of the masonry constitutive laws, for example, asymmetry in tension and compression, high nonlinearity in compression and brittle cracking, make the analysis of masonry structures an arduous task.

URM walls, columns, and piers are three of the most widely used types of masonry members. Their applications are not limited to masonry structures; they are also frequently used in mixed structures, either designed as load bearing or only as free-standing members. These masonry members, though not designed to bear out-of-plane lateral loads, may undergo unexpected out-of-plane lateral forces from earthquakes, wind, soil, and/or hydraulic pressure. The existence of out-of-plane lateral forces may pose a severe risk to the stability of URM compression members. Because of the low tensile strength, flexural tension cracks masonry and reduces the effective (i.e., uncracked) depth of cross-section and the flexural stiffness of the member along the weak (lateral) axis. This action increases lateral deflection and amplifies second-order moments, which, in turn, further reduces the effective depth. As a result, the vertical load-carrying capacity is lowered with potentially serious consequences.

Until now, this problem has not been addressed in current US code provisions [2]. However, the potential threat posed by the out-of-plane lateral loads has been recognized.

* Corresponding author. Tel.: +1 612 626 1540.
E-mail address: schul088@umn.edu (A.E. Schultz).

0141-0296/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.engstruct.2004.11.018

This paper concerns the influence of out-of-plane lateral loads on the behavioral phenomena and buckling capacity of concentrically or eccentrically compressed URM members.

2. Literature review

In recent years, growing attention has been paid to the stability of slender URM members under out-of-plane lateral loads. Substantial theoretical work has been done on the analytical and numerical simulation of the buckling behavior of URM members. Although some members (e.g., walls) are bidimensional, the analysis can be advantageously carried out by idealizing the member as a beam-column if the effects of lateral edge restraints are negligible [3]. Many studies treat URM members as a beam-column by means of a two-dimensional model with the assumption that its cross-section remains plane and normal to the longitudinal fibers of the bent member.

2.1. Analytical simulation

Most analytical simulation is based on the solution to the governing differential equation derived with reference to the cracked [4–6] or partially cracked member [3,7–12]. The former assumes that the cracked region involves the whole member, while the latter also considers the presence of an uncracked region. The analytical solutions hitherto have been dealing with prismatic members with a rectangular cross-section.

In most cases, masonry is assumed to have no tensile strength, and a relatively simple stress–strain relationship in compression is used, for example, linear elastic [4–6], non-linear monomial elastic [3,11], or linear elastic with bounded compressive strength and deformability [12]. However, very few investigations have considered material tensile strength. Chen and Atsuta [7] adopted an elastic–perfectly plastic stress–strain relationship with limited ductility and strains in tension and the governing equation was derived based upon the moment–curvature-curve method. Frisch-Fay [8–10] studied the stability of compression members made of materials which resist little tension and exhibit a linear relationship between compressive stresses and strains.

All the aforementioned analytical solutions were obtained for a particular combination of support and loading condition. The stability of a cantilever member subjected only to a concentrated eccentric load at the top is the most intensively studied case [4,7–9,12,13]. The case of a cantilever member under eccentric gravity loads [14] or its own weight [5,10] has also been investigated. Only a few papers addressed the stability of a cantilever member under simultaneous vertical and lateral loads, among which are those by Romano et al. [11] (simultaneous eccentric vertical and concentrated lateral loads at the top), and Ganduscio and Romano [3] (simultaneous vertical load at the top, self-weight, concentrated lateral load at the top, and distributed lateral load along the height). Recently, Schultz and Mueffelman [6] deduced the formulas for predicting the critical load of a masonry member under four different combinations of restraint and lateral loading condition, namely simply supported member under equal end-moments, simply supported member with a uniformly distributed lateral load, cantilever member with a concentrated lateral load, and cantilever member with a uniformly distributed lateral load.

The analytical study of unreinforced masonry compression members has yielded a number of closed-form formulas for computing the critical load. However, in order to avoid overcomplicated manipulations, all the formulas presumed a relatively simple stress–strain relationship and a particular load and restraint condition. Regrettably, these formulas were derived for a specific case, and many are still too complicated for practical use.

2.2. Numerical simulation

As stated before, analytical solutions have been obtained for a particular combination of load and restraint condition assuming a relatively simple constitutive law. Nevertheless, numerical methods are necessary in order to include material nonlinearity, uncracked regions, various load and restraint conditions (e.g., indeterminate), different cross-sections (e.g., circular or hollow), or even non-prismatic members (e.g., stepwise or tapered shapes as widely used in monuments).

In modeling masonry stability behavior, there are three basic approaches to handling the mortar-bed joints [15]: they are either simply smeared out (i.e., macromodeling), or represented by masonry unit–mortar interfaces (simplified micromodeling), or by continuous elements (detailed micromodeling). Whichever approach is chosen principally depends on the desired scale. Representing mortar-bed joints by continuous elements requires separate analysis of the mortar-bed joints and the use of an actual stress–strain relationship for the two materials. Hence, it provides a detailed representation of the stress distribution. A mixed finite element and finite difference analysis considering separately the masonry unit and the bed mortar was carried out by Payne et al. [16]. The unit–interface approach neglects the properties of the mortar and models the joints as potential lines of failure due to cracking. It is better suited for two-way dynamic analysis where load reversals may occur. It is mainly used to study the in-plane behavior of unreinforced masonry [17], but recently its application has been extended to out-of-plane analysis [18]. In the smeared joint approach, the unit–mortar composite is treated as a homogeneous medium whose mechanical properties average the effects of the interacting materials of masonry unit and mortar bed. The units, mortar and interfaces are globally represented by the same element. This approach is simple, efficient, and appropriate for modeling the global behavior of many URM members. It has been shown that the macromodeling approach is also capable of a rigorous

Download English Version:

https://daneshyari.com/en/article/10287145

Download Persian Version:

https://daneshyari.com/article/10287145

Daneshyari.com