Engineering Structures 33 (2011) 1955–1965

Contents lists available at ScienceDirect

Engineering Structures

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

Nonlinear response of masonry wall structures subjected to cyclic and dynamic loading

José Fernando Sima *, Pere Roca, Climent Molins

Department of Construction Engineering, Technical University of Catalonia, Barcelona, Spain

ARTICLE INFO

Article history:
Received 3 December 2009
Received in revised form
28 January 2011
Accepted 28 February 2011
Available online 9 April 2011

Keywords:
Masonry wall
Nonlinear analysis
Cyclic loading
Dynamic loading
Generalized Matrix Formulation

ABSTRACT

The assessment of the dynamic or seismic performance of complex structures often requires the integration in the time domain of the structural equation of motion in the frame of a nonlinear analysis. Although sophisticated methods have been developed for the nonlinear analysis of masonry wall structures, including the macro- and micro-modeling approaches, these require large computational effort still limiting the extent and complexity of the structures analyzed. This paper presents an alternative method based on the Generalized Matrix Formulation for masonry skeletal structures and load bearing wall systems, which has been proved as an efficient formulation for the analysis of the strength capacity of these kinds of structures (Roca et al. (2005) [17]). The basic formulation has been complemented with a uniaxial cyclic constitutive model for masonry and a time integration scheme. The ability of the resulting approach to predict the nonlinear dynamic response of masonry structures is shown through its application to the time domain analysis of an experimental scale masonry building with available experimental results on its dynamic response.

1. Introduction

During the past two decades, structural analysis of masonry structures has experienced a significant progress thanks to the development of sophisticate computer methods for both static and dynamic analysis. These methods are based on two main approaches, namely macro- and micro-modeling. The first does not take into consideration any distinction between masonry units and joints, masonry being regarded as an equivalent continuous and homogeneous material. The average material properties are usually obtained by means of homogenization techniques (Pegon and Anthoine [1], Luciano and Sacco [2], Milani and Lourenço [3], among others). The micro-modeling approach consists of modeling individually the mortar joints and the masonry units [4]. In some cases, simplifications on the micro-modeling have been introduced by using zero-thickness interfaces for the joints [5,6]. Although the two approaches afford the simulation of many aspects of the complex nonlinear behavior of masonry, they both (an especially micro-modeling) require still large computational effort preventing their application to the study of large and complex masonry structures. This limitation is even more evident when the assessment of complex masonry structures by means of time history analysis is considered. Alternative efficient methods, allowing the time history nonlinear analysis of masonry wall structures with a reasonable grade of accuracy and computational effort, are still necessary. Some of these alternative methods are based on modeling wall masonry buildings as equivalent frame systems.

Due to its large advantage in terms of computational effort, the possibility of using equivalent frames to model masonry wall systems has been explored since long time ago. Among the first attempts, Karantoni and Fardis [7], utilized this approach to carry pushover analysis using a nonlinear static analysis and compared the results with more detailed FEM models. These authors identified the main limitations and problems of the method, which were later overcome thanks to further sophistications in the description of the material and connections. Through their pioneering work, Magenes and Calvi [8] and Magenes and Della Fontana [9] provided a powerful tool (the SAM method) for the seismic pushover analysis of masonry buildings using rigid links to improve the description between piers and lintels and appropriate inelastic models to take into account the wall's flexural and shear failure. The method was validated by comparison with full scale experiments and FEM numerical results on the seismic response of multi-story masonry building façades. The method was later extended to the analysis of 3D systems [10]. Further applications were developed by Kappos et al. [11] and Salonikios et al. [12], among others.

Seismic analysis of wall systems by frame equivalent modeling is at present experiencing significant attention. Belmouden and Lestuzzi [13,14] have formulated a linear finite element including two multilayer connection hinges to model the deformations

* Corresponding author. Tel.: +34 934017380; fax: +34 93 4054135.
E-mail address: jose.fernando.sima@upc.edu (J.F. Sima).

0141-0296/$ – see front matter
doi:10.1016/j.engstruct.2011.02.033