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On safety assessment and base isolation of heavy non-structural monolithic objects

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Abstract

Under seismic actions heavy non-structural objects, which are usually placed at the top of existing constructions, may constitute a danger to human lives and a considerable loss for world heritage. In this contribution, safety assessment of non-structural monolithic objects is discussed through the illustration of a case study, which concerns seismic protection of eleven ancient marble decorative pinnacles placed at the top of a three-arched masonry city gate in Ferrara (ITALY). A method for assessing the safety of the underlying masonry structure under the action of seismic excitations is outlined and the amplification of the ground motions due to the presence of such structure is evaluated.

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Keywords: Seismic Isolation, Masonry, Monolithic Objects, Non-structural Elements.

1. Introduction

Many research efforts have been devoted, in the past, to devise effective seismic protection systems for heavy artwork, sculptures, pinnacles, merlons (see e.g. Fig. 1b), which do not have a structural function but belong to world heritage and, in many cases, have an inestimable value; for an introduction to this subject the reader is addressed to [1], [2]. The aim of the present contribution is to examine more in-depth some aspects related to the case study of the seismic protection through base isolation of eleven ancient marble pinnacles placed at the top of the three-arched masonry city gate in Ferrara, Italy, portrayed in Fig.1a. The three-arched masonry city gate was built in Ferrara Italy

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between 1703 and 1704 a.C (Fig. 1a). The marble pinnacles placed at the top of the gate have mainly a decorative purpose and their slenderness, coupled with their considerable mass, makes them highly vulnerable to seismic actions so that they cannot be considered safe. This case study has been recently described and analyzed by the authors in [3, 4], where a specific base isolation system based on the use of multiple double concave curved surface steel sliders has been devised; nevertheless, in order to assess the effectiveness of the isolation system in preventing rocking and overturning of the pinnacles, an accurate evaluation of the dynamical response of the underlying masonry construction can be helpful.

(a) (b)

Fig 1. (a) Three-arched masonry city gate, Corso Giovecca, Ferrara, Italy; (b) Masonry merlons belonging to the Castle of San Felice sul Panaro, Italy, (orthophoto).

For this reason and differently from the previous works, the present paper is mainly focused on the investigation of the dynamical behavior of the three-arched masonry construction and of the amplification of the ground motions due to its presence. The definition of suitable incremental constitutive relationships that correctly accounts for all the dissipation mechanisms of masonry is a completely open research subject. Recently, simplified and/or heuristic approaches such as macroelement models [5], rigid body and spring models [6] combined finite and discrete elements [7] have been successfully used for seismic analyses of unreinforced masonry structures. For the problem at hand, it can be shown that overturning of the pinnacles occurs when the masonry structure, though undergoing damage, is still very far from collapse [3]. Thus, a time-history analysis of the structure is carried out assuming an elastic behavior of masonry, in which damping coefficients have been suitably defined. The paper is organized as follows. In Section 2 the underlying three-arched masonry city gate structure is characterized, performing a natural frequency analysis and pushover analyses. In particular modal pushover analysis (MPA) [8, 9] have been employed. In Section 3, the evaluation of the amplification effect of the underlying masonry structure has been discussed.

2. Characterization of the three-arched masonry structure

2.1. In-plane push-over analysis

Employing the finite-element analysis code DIANA [10], in-plane capacity curve for the masonry structure has been determined through a non-linear incremental finite element analysis, using a force distribution proportional to the principal in-plane vibration mode, which has been obtained through a natural frequency analysis. The finite element model used for the analysis is shown in Fig. 2a, along with the main four modal shapes. A total strain elastic-plastic damaging constitutive law is assigned. The obtained in-plane capacity curve (shown in Fig. 3a) relates the total shear force *Fb* applied at the base of the structure with the in-plane displacements d_c of a control point which has been chosen as the medial point placed on one of the short sides of the construction, at a height of 3.00 m.