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Semi-active control of the rocking motion of monolithic art objects

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ABSTRACT

The seismic behaviour of many art objects and obelisks can be analysed in the context of the seismic response of rigid blocks. Starting from the pioneering works by Housner, a large number of analytical studies of the rigid block dynamics were proposed. In fact, despite its apparent simplicity, the motion of a rigid block involves a number of complex dynamic phenomena such as impacts, sliding, uplift and geometric nonlinearities. While most of the current strategies to avoid toppling consist in preventing rocking motion, in this paper a novel semi-active on–off control strategy for protecting monolithic art objects was investigated. The control procedure under study follows a feedback–feedforward scheme that is realised by switching the stiffness of the anchorages located at the two lower corner of the block between two values. Overturning spectra have been calculated in order to clarify the benefits of applying a semi-active control instead of a passive control strategy. In accordance with similar studies, the numerical investigation took into account the dynamic response of blocks with different slenderness and size subject to one-sine pulse excitation.

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1. Introduction

While many studies and codes are devoted to the seismic protection of existing buildings and in particular of museum buildings, the protection of the contents of museums, e.g. art objects on display or kept in storage, has received much less attention by the earthquake engineering standards. This notwithstanding, in the last years the protection of museum collections against seismic hazard is becoming a critical issue.

The past and recent seismic events have clearly shown the high vulnerability of art objects, and of museum contents, even in case of moderate earthquakes. Indeed, the art objects in many museums are displayed so that stability is not ensured during seismic events, and storage areas are often overloaded without any consideration for the seismic risk. The seismic mitigation of art objects requires a multidisciplinary approach in order to find a compromise between safety, conservation and exhibition.

From a structural point of view, the seismic behaviour of art objects can typically be analysed within the context of the dynamic response of rigid bodies. The literature counts a large number of analytical studies on the nonlinear dynamics of rigid blocks, starting from the pioneering work of Housner in 1963 [1]. The motion of rigid blocks on a rigid plane can be

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classified into six types: rest, slide, rotation, slide–rotation, translation jump and rotation jump. The equations of motion, transitions of motion and the motion after the impact between the block and the floor, in the presence of horizontal and vertical accelerations, were investigated by Ishiyama in 1982 [2]. Depending on the form and magnitude of the excitation [2,3] and on the geometry and mass distribution of the objects, the artefacts can experience all the types of motion mentioned above. Among different cases, a particular and fundamental role is assumed by the rocking motion that causes objects to fall from their supports and/or to collide with other objects.

To mitigate the damage due to the rocking motion and to limit the probability of overturning, four different strategies are currently used [4]: (i) lowering the centre of gravity of the artefacts; (ii) adjusting the base-to-height ratio proportions of the art objects; (iii) fixing the objects to the floor/wall and (iv) separating the objects from the ground using base isolation devices. The efficacy of the first two strategies must be attributed to the dynamics of rigid block. During the rocking motion of a rigid block the restoring force is essentially due to its own rotational inertia. Lowering the centre of gravity of an artefact allows to increase, for a given value of the horizontal external action, the ratio between the restoring and the overturning moment of the system, and consequently its stability. The second strategy, i.e. adjusting the base-to-height ratio proportions, can be easily explained in terms of slenderness on overturning, a concept introduced for the first time by Housner [1] and subsequently investigated by several authors [5,6]. These two strategies, as well as anchoring the objects to the ground, must be used with caution because of the possible high forces transmitted to the artefact. In this case, the art object is forced to bend and deform, instead of oscillating rigidly around the two corners. Hence, failure due to excessive stress is likely, especially in presence of weak and cracked material.

In contrast to the significant amount of theoretical research on the response of free-standing blocks, there are relatively few studies on the response of anchored objects. The in-plane behaviour of a rigid block on a rigid plane anchored with elastic–brittle restraints was studied by Dimentberg et al. [7] and by Makris et al. [8]. In particular Dimentberg et al. investigated the behaviour of anchored blocks excited by white noise, while Makris et al. studied the response of them to pulse-type ground motions, showing that there is a finite frequency range where the conclusions drawn by Dimentberg et al. do not hold concerning the response. The study about pulse-type excitations inferred that a frequency range exists where a free-standing block has a better performance than an anchored block.

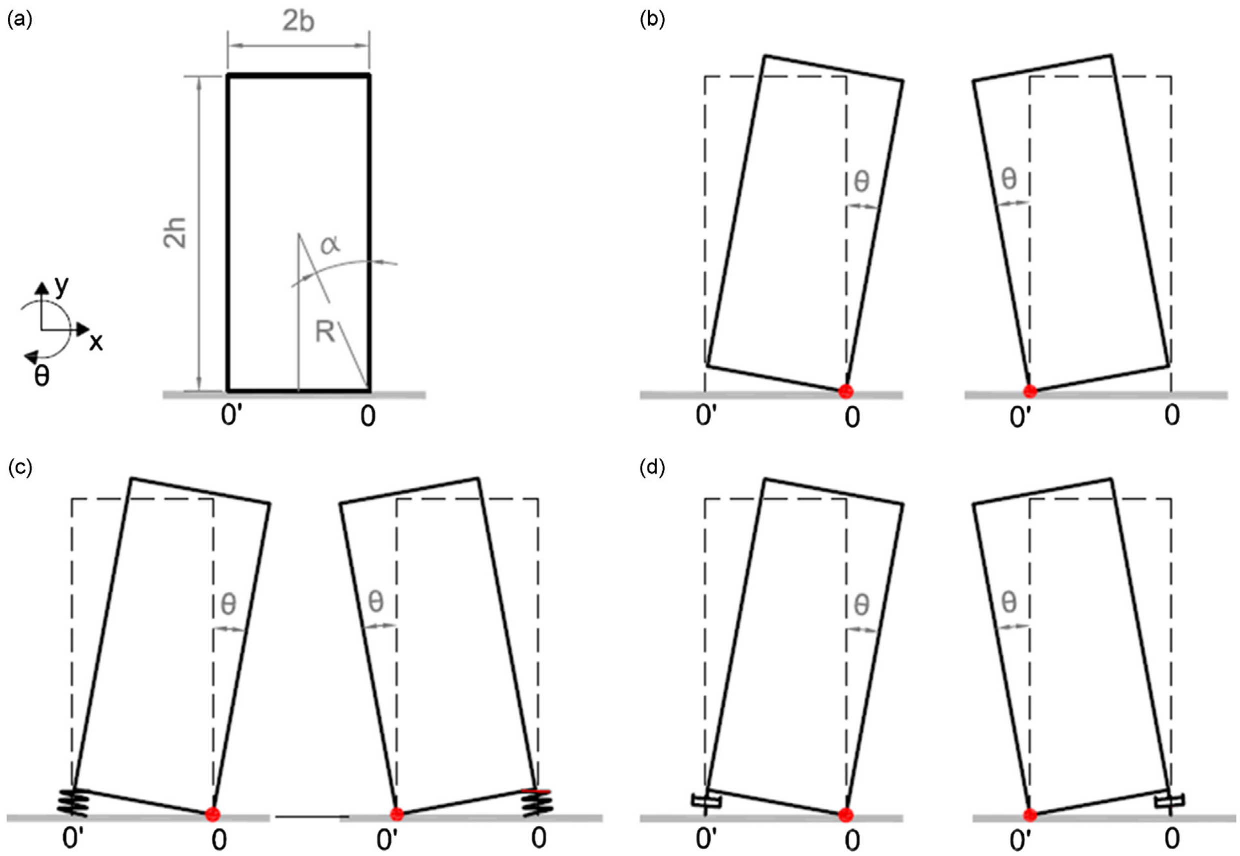

Fig. 1. (a) Idealisation of an artefact as a rigid body, positive convention of displacements and geometrical parameters of the block; (b) mechanical model of unanchored rigid block; (c) mechanical model of rigid block anchored with unilateral elastic–brittle anchorages (reacting only in tension); (d) mechanical model of rigid block anchored with damper devices.

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