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Effectiveness of oscillating mass damper system in the protection of rigid blocks under impulsive excitation

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ABSTRACT

In this paper the effects of a mass damper on the rocking motion of a non-symmetric rigid block, subject to one-sine pulse type excitation, is investigated. The damper is modelled as a single degree of freedom oscillating mass, running at the top of the block and connected to it by a linear visco-elastic device. The equations of rocking motion, the uplift and the impact conditions are derived and the results are obtained by numerical integration of these equations. An extensive parametric analysis is performed, by taking fixed the geometrical characteristics of the block. The frequency and the amplitude of the excitation, the mass ratio and the period of the oscillating mass are taken as variable parameters in the analyses. The main objective of the study is to understand if it is possible to find the optimal properties of the oscillating mass, capable to make more difficult the overturning of the body. The results show that the presence of the mass damper, if correctly designed, leads to a general improvement of the response of the system. Curves providing the optimum value of the characteristics of the mass damper versus the parameters characterizing the excitation, are finally obtained.

1. Introduction

The mechanics of rigid bodies is a classical and widely examined topic in the scientific Literature. After the pioneering papers [1,2], many papers dealt with this specific issue. Often the studies referred to art objects subject to different types of excitation, such as one-sine pulse and harmonic excitations [3–5], earthquake excitations [6–8] and random excitations in the form of modulated white noise [9]. The majority of the works investigated the behaviour of two-dimensional models of symmetric rigid blocks. Only few articles [10–12] included the geometrical asymmetry.

In some important papers general aspects related to the dynamics of rigid bodies were studied. Specifically, in [13,14] the definition, in the form of maps, of criteria for the different phases of motion was obtained; in [4,15] the existence of survival regions which lie above PGA (Peak Ground Acceleration) associated with the first occurrence of overturning were pointed out; in [16] the correct definition of the impact occurrence was studied. More complex configurations were also examined, as in [17] where the behaviour of two stacked rigid blocks was considered, or in [18,9] where block was laid on a flexible foundation, or in [19,20] where a system of three rigid block with unilater deformable contact was analyzed. Rigid bodies, representing art objects, placed on isolated base were studied as well in [21]. Regarding this latter configuration, the sliding and rocking of the rigid block partially outside the isolated base was taken into account in [22] while the effectiveness of the base isolation on the reduction of the dynamic response of an isolated rigid block, placed on a multi-story frame, was investigated in [23].

A three-dimensional approach for the study of the dynamics of rigid bodies was presented in only a few papers. Some of these dealt with the motion of a disk of finite thickness [24,25], the wobbling of a frustum [26] or sloshing in a tank [27]. In [28–30] a three-dimensional model of rigid block with a rectangular base were developed to study slender bodies such as statues and obelisks.

Although the Authors of this paper in [28] demonstrated that a three-dimensional model of a rigid block should be used to correctly evaluate the collapse event of a near-square-based rigid block, here a simpler 2D model is used. This is justifiable since the rigid block considered here is always assumed to possess a rectangular base with one side considerably larger than the other. In this case, the only possible rocking motion is the one around the longer side of the rectangle. Hence, to describe this motion, a classical 2D model of the rigid block is sufficient.

In some papers, such as [31,32], the presence of double-side unilateral constraints and other devices and their effects, in many

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cases positive, on the rocking motion of the block was investigated. The use of particular systems, coupled with the rigid block and working as a mass damper, are not very frequent. For example in [33] a sloshing water damper was used to control the motion of a rigid block. More recently, in [34,35], a study on the use of a pendulum used to control the rocking response of a rigid block was presented. In these papers it was found that the pendulum, if correctly designed, leads to a general improvement of the response of the system, since the overturning of the block occurs for values of the amplitude of the base excitation higher than those observed where no mass damper was used. However, since both the rigid block and the pendulum are nonlinear structures, it is difficult to determine the optimal characteristics of the mass damper. To overcome this problem, in the present paper, a single degree of freedom oscillating mass, running at the top of the block and connected to it by a linear visco-elastic device, is used as mass damper. Being a linear system and possessing a proper period of oscillation, it is possible to investigate the relationships that exist between the period of the external impulsive one-sine excitation and the linearized period of the block. Even if both the two previous protecting strategies use the principle of the tuned mass damper, they can be used in different cases. For example, the pendulum mass damper could protect trilithic structures, where the pendulum has enough space to oscillate, while the oscillating mass damper could protect big storage boxes, transformers and so on.

The equations of motion are obtained by using a Lagrangian approach, while the impact conditions are written by means of the conservation of the angular momentum before and after an impact. The oscillating mass is considered sufficiently smaller than the block and concentrated in a point. An extensive parametric analysis is performed, by taking fixed the geometrical characteristics of the block. The frequency and the amplitude of the excitation, the mass ratio and the period of the oscillating mass are taken as variable parameters in the analyses. The main objective of the study is to understand if it is possible to find the optimal properties of the oscillating mass, capable to make more difficult the overturning of the body.

The results show that the presence of the mass damper, if correctly designed, leads to a general improvement of the response of the system, since the overturning occurs with more difficulty. Curves, providing the optimum value of the characteristics of the mass damper versus the parameters characterizing the excitation, are obtained. A threshold frequency of the one-sine excitation is found, above which the use of the mass damper is useless. This frequency depends on the geometrical characteristics of the block. In a forthcoming study this threshold frequency versus the geometrical quantities characterizing the block will be investigated.

2. Mechanical system

The mechanical system is constituted by a rigid body in the shape of parallelepiped and an oscillating mass, connected to the block by a linear visco-elastic device, running at the top of the block (Fig. 1). The system is characterized by a few geometrical parameters; specifically, H and B are the heigh and the base of the block, respectively, h is the height of the oscillating mass m with respect to the upper side of the block. Only horizontal eccentricities e are considered. Specifically, e is the distance between the geometrical centre of the parallelepiped M and the centroid of the block G. Finally, k_m and c are, respectively, the stiffness and the viscous coefficients of the linear device connecting the mass to the block and $x_g(t)$ is the external excitation.

It is assumed that the block can undergo to only rocking motion. No sliding motion is allowed, since the block possesses a slenderness $\lambda = H/B$ sufficiently large, for which only the rocking motion can manifest itself. Under this hypothesis, the possible phases of the motion can be only two: the full-contact phase and the rocking phase. It is necessary to obtain both the equations of motion of these phases and the transition conditions among them.

The two Lagrangian parameters, necessary to describe the motion, are: the angle $\vartheta(t)$, which measures the amplitude of the rocking motion and the displacement $x(t)$, which describes the amplitude of the oscillation of the upper mass m. In Fig. 2 it is shown when these parameters are positive or negative.

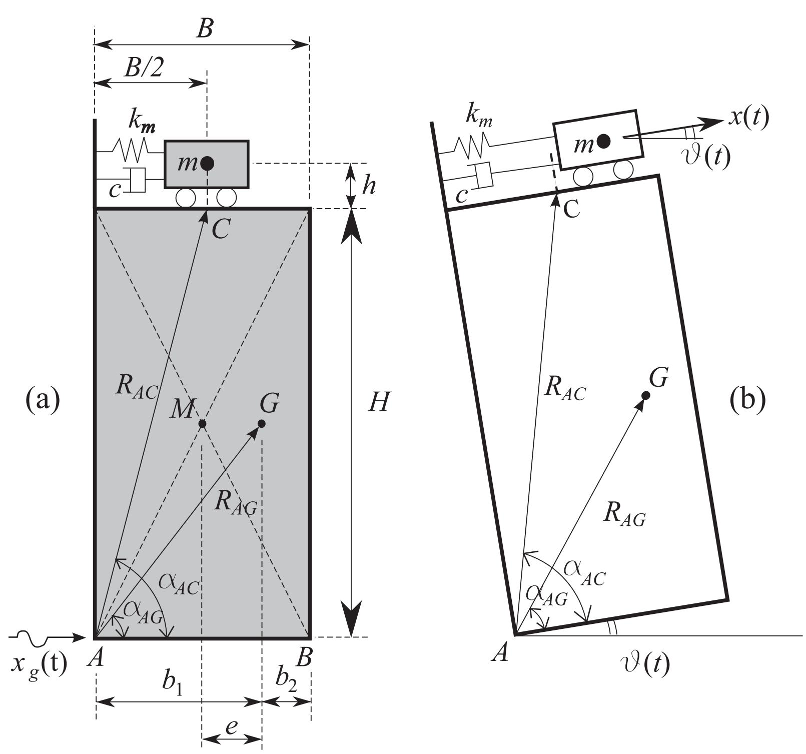

Fig. 1. Rocking around the left corner: (a) geometrical characteristics and (b) rocking around the left corner A.