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Nonlinear rocking of rigid blocks on flexible foundation: analysis and experiments

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Abstract

Primarily, two models are commonly used to describe rocking of rigid bodies; the Housner model, and the Winkler foundation model. The first deals with the motion of a rigid block rocking about its base corners on a rigid foundation. The second deals with the motion of a rigid block rocking and bouncing on a flexible foundation of distributed linear springs and dashpots (Winkler foundation). These models are two-dimensional and can capture some of the features of the physics of the problem.
Clearly, there are additional aspects of the problem which may be captured by an enhanced nonlinear model for the base-foundation interaction. In this regard, what it is adopted in this paper is the Hunt-Crossley nonlinear impact force model in which the impact/contact force is represented by springs in parallel with nonlinear dampers. In this regard, a proper mathematical formulation is developed and the governing equations of motion are derived taking into account the possibility of uplifting in the case of strong excitation. The analytical study is supplemented by experimental tests conducted in the Laboratory of Experimental Dynamics at the University of Palermo, Italy. In this context, due to their obvious relevance for historical monuments, free-rocking tests are presented for several marble-block geometries on both rigid and flexible foundations. Numerical vis-à-vis experimental data are reported, supporting the usefulness and reliability of the proposed approach.

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Keywords: Rocking motion; Nonlinear contact model; Flexible foundation;

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1. Introduction

The behavior of block-like structures allowed to rock due to base excitation has been a longstanding problem of technical interest and still attracts the attention of a significant number of researchers.

A number of alternative analytical models have been proposed to study the rocking dynamics. However, two models are primarily used to describe the rocking of rigid bodies subjected to ground motion; they are two-dimensional and afford a reasonable representation of the phenomenon.

The first model, hereinafter referred to as the Housner model (HM) [1], deals with the motion of a rigid block rocking about its base corners on a rigid foundation.

The second model, known as Winkler foundation model (WFM), deals with the motion of a rigid block rocking on a flexible foundation of distributed linear vertical springs and dashpots [2].

Although the rocking phenomenon has been extensively studied, most previous researches have been analytical in nature. Moreover, many experiments on rocking blocks have considered the behavior of rigid blocks on rigid foundations, while the problem of rigid blocks on flexible foundation is less investigated [3].

To further study this complex phenomenon, as well as to take into account the aspects which may arise during the rocking motion of rigid blocks on flexible foundations, in this paper a nonlinear model is used for the base-foundation interaction. Specifically, the Hunt- Crossley nonlinear impact force model [4] is adopted herein; thus, the foundation is treated as a bed of continuously distributed linear tensionless springs in parallel with nonlinear dampers. Note that this model is commonly used in the open literature to represent the nonlinear nature of impact and contact phenomena. The pertinent governing equations of motion are derived taking into account the possibility of uplifting in the case of strong excitation. Further, the analytical study is supplemented by a large number of experiments conducted in the Laboratory of Experimental Dynamics at the University of Palermo, Italy. In this regard, due to their obvious relevance for historical monuments, free-rocking tests are performed for several marble-block geometries on both rigid and flexible foundations. Numerical vis-à-vis experimental results are reported for the proposed model, demonstrating the reliability and accuracy of the proposed formulation.

2. Rocking of a rigid block

Consider a rectangular rigid block with mass m and polar moment of inertia I_{cm} about the center of mass cm, as shown in Fig. 1(a). The variable R is the distance of the base corners from the center of mass, situated at height h above the base of width $2b$. Further, let θ_{cr} be the critical tilt-angle, that is, the maximum angle to which the block can be tilted without overturning under the action of gravity, g, alone.

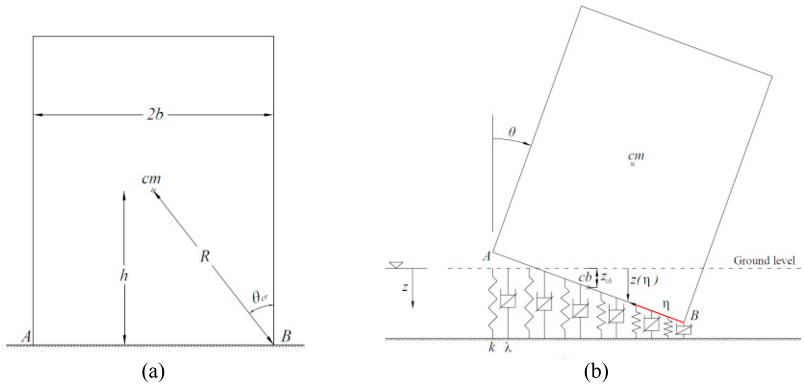

Fig. 1: Rocking of a rigid block: a) Block geometry; b) Rocking block on nonlinear flexible foundation.

The block is free to rock and bounce on a flexible foundation. For simplicity, the center of the base cb is restricted to vertical relative motion only [2]. Thus, two generalized coordinates are sufficient to specify the configuration of the block relative to the foundation. Specifically, the vertical displacement z_{cb} of the center of the base cb from the undeformed surface of the foundation (positive downward), and the rotation θ of the block from its