(154) RESPONSE OF INTERIOR OBJECTS TO EARTHQUAKES

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ABSTRACT

Shaking table tests were conducted to investigate the response of rectangular wooden blocks and block assemblies of various sizes and slenderness to harmonic and earthquake base excitation. The shaking tests were followed by an analytical and a numerical study of response of single blocks and block assemblies. The analytical study was aimed at establishing criteria for the initiation of rocking and of overturning in response to harmonic base motion and consisted of solving numerically the differential equations of motion of a rigid block on rigid foundation. The numerical study, in the course of which the response of both single blocks and block assemblies was examined, was implemented by means of the Distinct Element Method (DEM). Prior to the DE simulation of actual shaking tests, preliminary analyses were conducted to confirm numerical stability and to evaluate material and damping parameters. Comparing the recorded time histories with those given by the analytical study and the DE simulation, good agreement was found. The Distinct Element model in use appeared to follow the highly nonlinear motion of rigid body assemblies faithfully to reality. On the basis of the results, provided that the necessary parameters are carefully estimated, the employed DE model can be regarded as an appropriate tool to simulate the response of rigid body assemblies to dynamic base excitation.

INTRODUCTION

Residents of buildings are subjected to injuries from displacement of surrounding objects (overturning of shelves, falling of overhead articles, etc.).Interior objects often overturn in response to the intense ground shaking, inflicting potential danger to the inhabitants. The material loss due to the damage to the overturned and fallen objects was also considerable. With the analytical computation of motion of rigid body assemblies exposed to dynamic excitation being highly nonlinear, and as such, extremely complex to derive analytically, explicit numerical approaches that can handle a large number of arbitrary shaped bodies and can regard various kinds of boundary conditions may be much more convenient to apply.

The problem of overturning of rigid bodies due to ground shaking has attracted many researchers' attention. Research in this field dates from the 19th century. Focusing on the rocking motion of a rigid block on a rigid base subjected to horizontal and vertical ground motions, a numerical procedure and a computer program were developed by Yim et al[1]. Ishiyama[2] also studied the response of a single block on a rigid foundation to harmonic and earthquake ground motion. The equations of motion of a rocking rigid block, considering sliding and bouncing, were formulated and solved numerically. New criteria of rocking and overturning with respect to peak ground acceleration and velocity were proposed. Dynamic behavior of a rocking rigid block

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supported by flexible foundations which allow for uplift was analyzed by Psycharis and Jennings[3]. In their work, two foundation models were compared, the Winkler foundation and a simpler two-spring foundation. They showed that it is permissible to model a continuous flexible foundation by means of a discrete, two-spring model when analyzing the dynamic behavior of a rigid block. The two-spring model they used to represent a foundation is very similar to the contact model of the Distinct Element program employed by the present authors. Psycharis[4] analyzed the response of a two-block assembly in which a rectangular block is placed on top of another. The analytic formulation of the solution of this highly nonlinear problem proved to be very complicated. Governing equations for all of the possible vibration modes were derived and the rate of energy dissipation was also evaluated for each mode.

Since the existing studies and simulation models are limited to represent either one block or two-block assemblies with simple boundary conditions, the authors seek an approach that is applicable to rather general models and boundary conditions. The Distinct Element Method (DEM), originally proposed by Cundall[5], was selected for the purpose of numerical simulation.

SHAKING TABLE EXPERIMENTS

A series of shaking table tests were conducted using rectangular wooden blocks of various sizes and *b/h* ratios. Single blocks as well as block assemblies were tested under horizontal sinusoidal input base motion of a frequency range of 1 to 6 Hz. All of the input motions and the response acceleration of every block were recorded for the purpose of a later comparison with the results from the numerical simulation.

DISTINCT ELEMENT SIMULATION

As a first step in the process the spring and dashpot constants for the contact model as well as the coefficient of friction were established. Then using the input motions recorded in the experiments the shaking tests were simulated by means of the DEM. Figure 1 shows a few frames of the animation of the response of two two-block columns, one freely standing and another by a wall, under a 3 Hz horizontal input base motion. To check the accuracy of the DE simulation criteria for rocking and overturning were compared with those from the shaking table tests.

AN EASY-TO-USE INFORMATION SYSTEM

On the basis of the results the authors began the implementation of an interactive computer software that is intended to facilitate the understanding of the importance of the problem of overturning internal objects for the general public. The intended system is a 'what will happen if' sort of visual package that will tell the user what is expectable to become of the interior on a certain floor of a building at a specific site in case of an earthquake. With this new system in use anyone, regardless of qualification, can obtain an idea of the reaction of interior objects to intense ground shaking. The user can freely set the conditions of the simulation. It is possible to specify the floor on which the apartment or office we inquire about is located (Figure 2); the user than shall select one of several historical earthquake motions as input base motion (Figure 3). What is left is only the arranging of the interior itself. Simply by clicking in the screen the user can choose a desired set of interior objects (Figure 4) that will be exposed to the motion of the specified floor computed from the input ground motion. Finally, the computed response of the interior objects is presented in a real-time animation (Figure 5) from which the importance of the problem will be very simple to perceive. The authors believe that this informative system will raise awareness to the importance of positioning of furniture and other sorts of potentially hazardous objects of interiors.

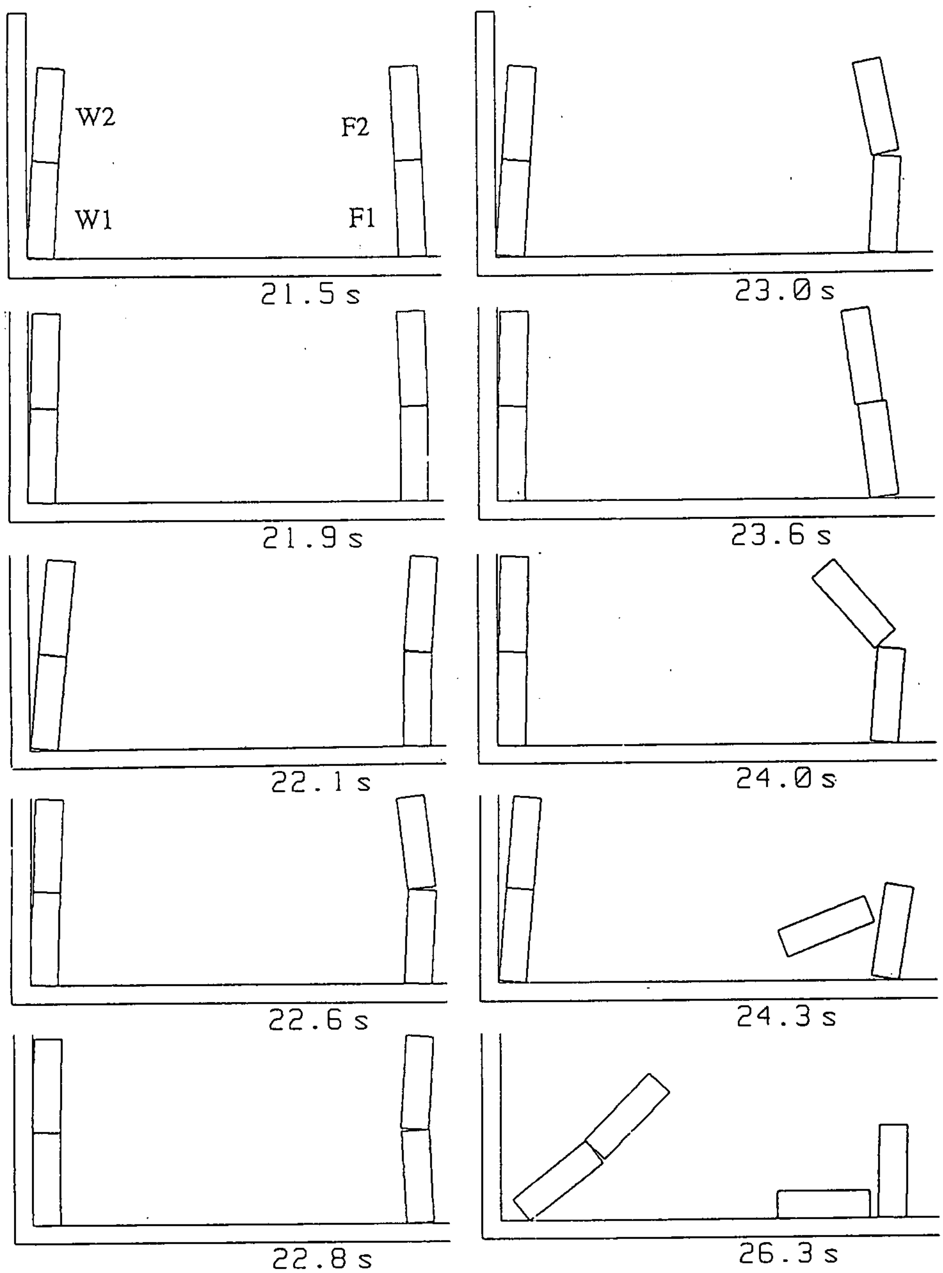

Figure 1. Response of two block columns to a 3 Hz harmonic base motion.

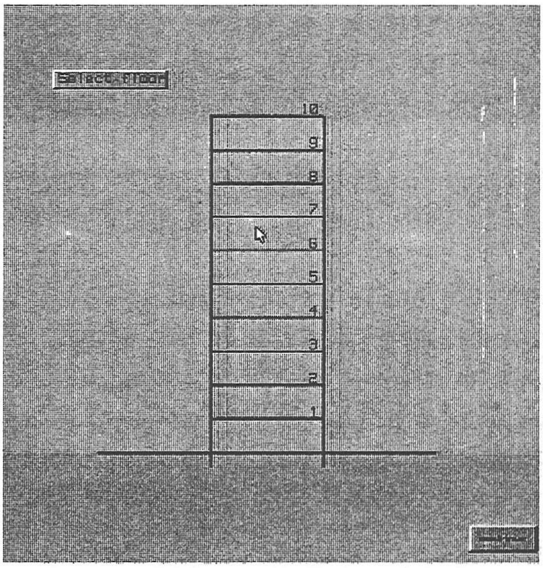

Figure 2. Selecting floor.

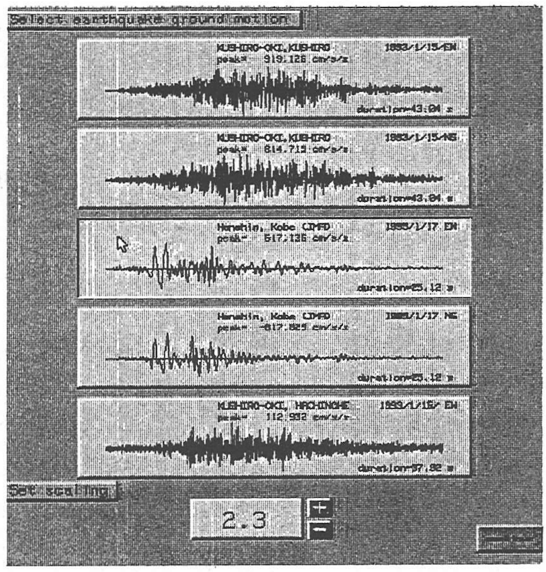

Figure 3. Selecting earthquake ground motion.

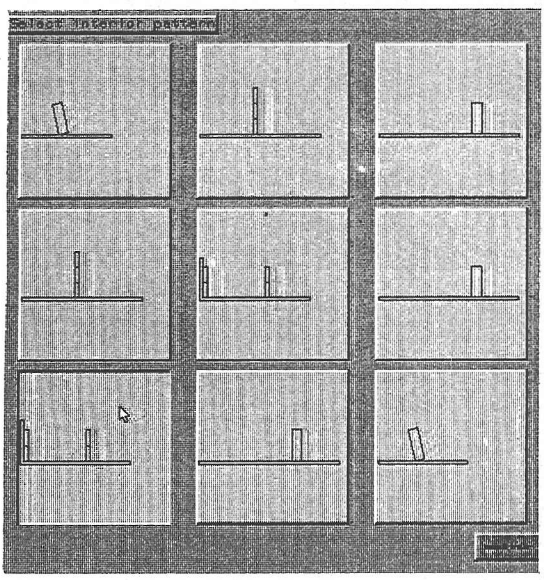

Figure 4. Selecting interior.

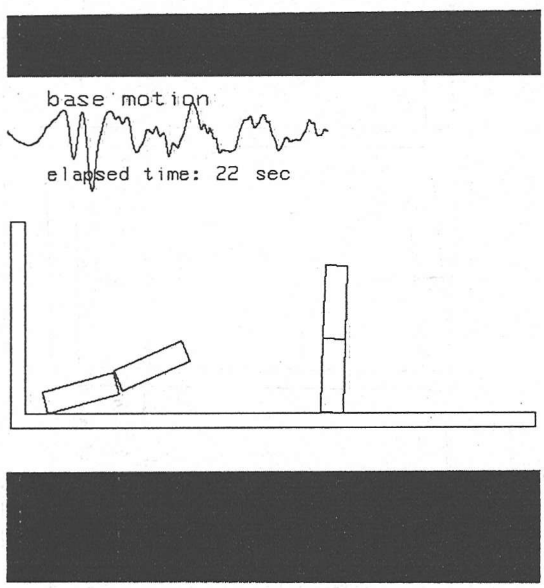

Figure 5. Real-time animation.

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