I - 452 RESPONSE OF RIGID BODY ASSEMBLIES TO DYNAMIC EXCITATION

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INTRODUCTION: Residents of buildings are subject to injuries resulting from the displacement of surrounding objects (overturning of shelves, falling of overhead articles, etc.). Being the analytical computation of the motion of rigid body assemblies exposed to dynamic excitation extremely complex, numerical approaches may be more convenient to apply. The problem of overturning of rigid bodies due to ground shaking has attracted many researchers' attention. Ishiyama (1982) studied the response of a single block on rigid foundation to harmonic and earthquake ground motion. New criteria of rocking and overturning with respect to peak acceleration and velocity were proposed. Recent studies extend the problem of rocking of a rigid block on rigid foundation to more complicated examples. Psycharis (1990) analyzed the simplest case of a two-block assembly in which one rectangular block was placed over the other. Since the existing studies and simulation models are limited to represent one block or two-block assemblies with simple boundary conditions, the present authors seek an approach applicable to general models and boundary conditions. The Distinct Element Method (DEM), which was originally proposed by Cundall (1971) is highlighted in this study as a tool to simulate the dynamic behavior of rigid block assemblies under base excitation.

SHAKING TABLE EXPERIMENTS: A series of shaking table tests were conducted using a two-directional shake table (horizontal and vertical components). Parallelepipeds glued from thin wooden plates were used for specimens (Figure 1). A series of tests on different combinations of blocks was conducted, using harmonic and natural earthquake excitations. The first combination was a column of three blocks (h=50 cm, b/h=0.3). Two columns, both of which were set up from two blocks (h=50 cm, b/h=0.3), one over another, were also tested. One of the columns stood freely while the other was set next to a wall firmly attached to the shake table. This setting is very similar to the that of cupboards and bookshelves seen at homes and offices.

NUMERICAL SIMULATION: Prior to the numerical simulation of the shaking tests, there were preliminary analyses conducted to determine the stiffness, damping and friction parameters of the Distinct Element (DE) model shown in Figure 2. The energy dissipation at contacts was represented by velocity proportional damping. An appropriate damping constant was identified by comparing the time history of the free vibration of a block with that by DE analysis (Figure 3).

RESULTS OF THE EXPERIMENT AND THE SIMULATION

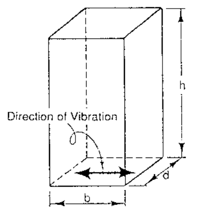
According to the results for the two-block columns, both the experiment and the simulation confirm that, at low frequencies the column by the wall loses stability later than the one that stands freely. Above 2 Hz the freely standing column fails later. Figure 4 shows a few frames of the animation of the behavior under 2 Hz harmonic base motion. Figure 5 and 6 present the criteria of overturning of the column by the wall and of the one that stands freely, respectively. Representative moments of the column of three blocks under 3 Hz harmonic base motion are shown in Figure 7. The criteria of overturning under harmonic excitation, are shown in Figure 8.

CONCLUSION: Quantitative difference in the results of the experiment and the simulation is rather small. The numerically computed behaviors are very much like those seen in the actual tests. Qualitatively, the Distinct Element model can be said to have performed well and the agreement with the test results is, with the exception of a limited number of points, good. Continuing the present study, the authors intend to perform the numerical simulation of the shake table tests in which natural earthquake excitation was applied.

REFERENCES: Cundall, P. A. "A Computer Model For Simulating Progressive, Large-scale Movements in Blocky Rock Systems." Proc. Int. Symp.on Rock Fracture, Nancy, France (1971):II-8.

Ishiyama, Y. "Motions of Rigid Bodies and Criteria for Overturning by Earthquake Excitations" Earthquake Engineering and Structural Dynamics 10. (1982):635-650.

Psycharis, I.N. "Dynamic Behavior of Rocking Two-block Assemblies." Earthquake Engineering and Structural Dynamics 19. (1990):555-575.



Block	Size [cm] b	h	d	k	b/h
Block 1	30	100	50	2.0	0.3
Block 2	22.5	75	37.5	1.5	0.3
Block 3	15	50	25	1.0	0.3
Block 4	7.5	25	12.5	0.5	0.3
Block 5	25	50	25		0.5
Block 6	20	50	25		0.4
Block 7	10	50	25		0.2

Figure 1. Table of specimens.

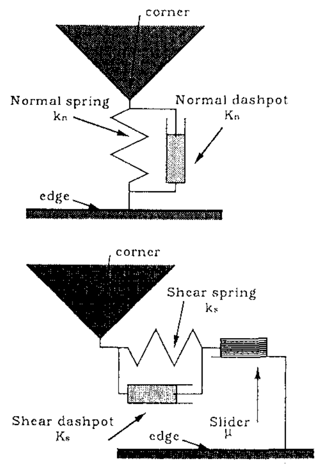


Figure 2. The DEM model.

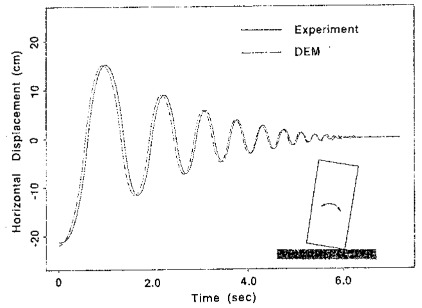


Figure 3. Time histories of free vibration.

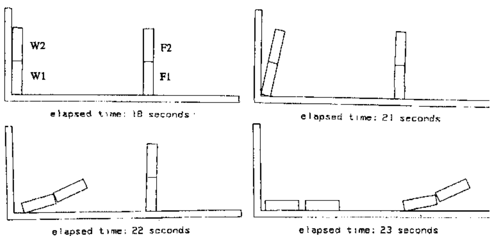


Figure 4. The two block columns under 2 Hz harmonic shaking.

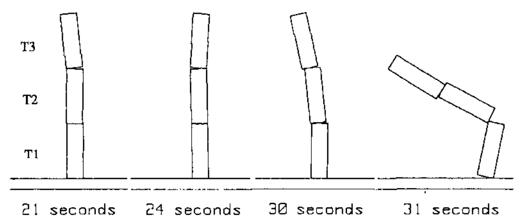
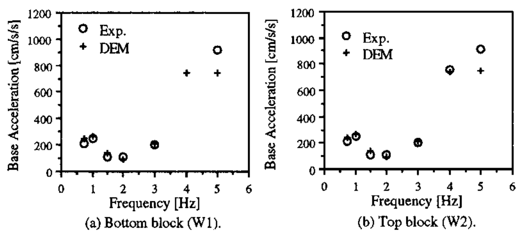
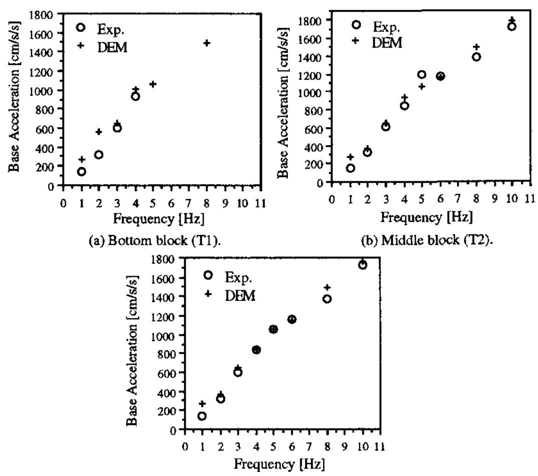


Figure 7. The three-block column under 3 Hz harmonic shaking.

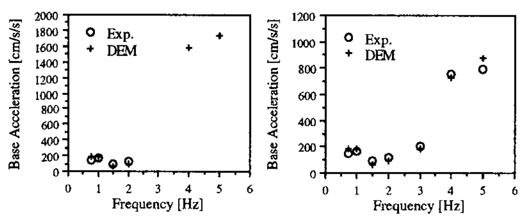


(a) Bottom block (W1). (b) Top block (W2).

Figure 5. Criteria of overturning of the two-block column interacting with wall.



(a) Bottom block (T1). (b) Middle block (T2). (c)Top block (T3).



(a) Bottom block (F1). (b) Top block (F2).

Figure 6. Criteria of overturning of the freely standing two-block column.

Figure 8. Criteria of overturning for the three-block column.