I-B 356

A STATISTICAL STUDY OF THE OVERTURNING OF RIGID BLOCKS ON A RIGID BASE DUE TO EARTHQUAKE EXCITATION THROUGH THE DISTINCT ELEMENT METHOD

University of Tokyo, Student Member: Tibor WINKLER
University of Tokyo, Member: Fumio YAMAZAKI
University of Tokyo, Member: Kimiro MEGURO

INTRODUCTION: Considerable time and effort has been expanded on the study of the problem of overuming of rigid, rectangular blocks on a rigid base since the 1880's. Several researchers tried to advance the state of the art, to examine the phenomenon and to propose yet more reliable criteria to depict it. Through the works of Milne (1881 and 1885), Kirkpatrick (1927), Housner (1963), Yim (1980) and Ishiyama (1982) it has been concluded that the effect of random waves, such as an earthquake, on the highly non-linear response of a ridig block on a rigid floor, cannot be studied in a deterministic manner and reliable conclusions cannot be drawn inferring from an individual example. Also, it has been shown that the latest existing criteria of overtunring are not reliable in case of earthquake excitation. To attain reliable criteria one must employ a method, as has been pointed out in the course of research of the subject, that accounts for the non-linear charcteristics of the response of the block, with which to compute response for a statistical approach that involves the examination of a large number of cases considering the randomness of the eartqhuake ground motion.

METHOD: For the purpose of computing response of rigid blocks on a rigid floor to earthquake base input the authors chose the Distinct Element Method (DEM) that had been proven applicable to similar problems previously (Winkler, 1995). As for earthquake ground motion as base input for the DE simulation a set of thirty horizontal earthquake records, sixty waves, was compiled from ten strongly damaging, well known earthquakes from around the world. These are the Imperial Valley Earthquake of October 15, 1979, the Northridge Earthquake of January 14, 1994, the Loma Prieta Earthquake of October 17, 1989, the Mexico City Earthquake of September 19, 1985, the Kushiro-Oki Earthquake of January 15, 1993, the Hokkaido-Nansei-Oki Earthquake of July 12, 1993, the Hokkaido-Toho-Oki Earthquake of October 4, 1994, the Sanriku-Haruka-Oki Earthquake of December 28, 1994, the Hogyoken-Nambu Earthquake of January 17, 1995 and the Chiba-Toho-Oki Earthquake of December 17, 1987. Records from the same earthquake at recording stations at different distances of the fault line along which the earthquake occurred were selected, thereby including various spectral characteristics due to attenuation and diverse site conditions. A requirement for intensity was that the Peak Ground Acceleration (PGA) of each wave must be greater than 100 gal. Figure 1 shows the distribution of PGA and PGV values in the dataset used in the analysis. The duration of the strong motion part of the waves was established in accordance with Trifunac and Brady (1975). One of the major aims of this work was to depict the likelihood of overturning with respect to more than one parameter of the earthquake motion simultaneously. To this end, all of the sixty waves were scaled so that their PGA values were identical. This scaling of the dataset was done in between 0.2g and 1.0g in 0.1g steps. Given these identical PGA values for the whole of a set it became possible to investigate the influence of ground velocity on the probability of overturning with respect to ground acceleration. This fashion of computation was then reversed to explore the effect of ground acceleration with respect to velocity. Apart from the existence of the so-called 'lower limit of acceleration required for overturning' (Ishiyama, 1982) there was not any clearly obvious trend manifested in the latter case, therefore attention from then onward was focused on the exploration of the former approach. In the course of this 'numerical experiment' a set of rigid blocks of various sizes and slenderness ratios, shown in Figure 2, were tested in the formerly described manner. Maxima of angular displacement for all of the blocks were noted.

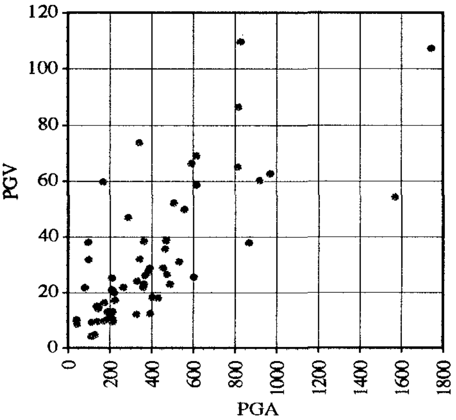

Figure 1. The distribution of PGA and PGV values in the earthquake dateset.

RESULTS: Figure 3 introduces the tendency that was discovered between PGV and angular displacement; on the vertical axis are the maximum values of rotation divided by the critical angle of rotation, which is the angle at which the Center of Gravity of the block is just above the edge it is pivoting about. It may be observed that beyond a certain threshold of PGV there is a clear tendency of overturning. Such tendencies were observed only in the range of PGA beyond West's criterion for rocking, $a = g \cdot b/h$, as was referred to by Isiyama (1982):

'the minimum of ground acceleration required for overturning'. Since the PGV values in the dataset are not perfectly uniformly distributed and, also, owing to the scatter of angular displacement vs. PGV values, it would be misleading simply to take the highest velocity value corresponding to a yet below 1.0 normalised rotation value for a criterion of overturning. It would seem more appropriate to compute probability of overturning for every velocity value, based on the trend in Figure 3, as a fractional number of the number of velocity values that resulted in overturning and the number of all of the velocity values, beyond the velocity value in question. To this end, the sixty pairs of PGV and rotation values were arranged in ascending order with respect to PGV and the last 20 values were not considered for reasons of statistical confidence. These statistical probability values were plotted vs. PGV and the best fit curve was sought in order to be able to quantify the clear trend beyond the bounds of the earthquake data that was used (Figure 4). From similar charts to the one in Figure 4, pertaining to different PGA values, it would be possible to infer to overturning risk throughout a range of PGA values as visualised in Figure 5; the curves indicate that beyond the above mentioned critical acceleration value, the velocity required for 90 per cent probability of overturning is approximately constant. This would mean that whether a rigid block overturnes or not in an earthquake depends, beyond West's lower acceleration bound, chiefly on velocity, so, consequently, it would seem safe to extend the validity of this PGV limit value to all values of PGA beyond West's acceleration threshold. In this way similar velocity values will be established for an array of blocks of different geometry and useful as well as reliable criteria of overturning will be proposed.

block no.	h/b	size factor	b [cm]	h [cm]
1	3	1	20	60
2		2	40	120
3		4	80	240
4	4	1	15	60
5		2	30	120
6		4	60	240
7	5	1	12	60
8		2	24	120
9		4	48	240
10	6	1	10	60
11		2	20	120
12		4	40	240

Figure 2. Table of rigid blocks tested in the analysis.

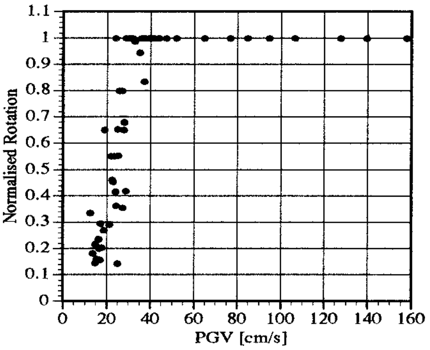

Figure 3. Normalised rotation versus PGV values of a block of h/b=4 and h=60 cm in response to sixty earthquake waves, all of PGA=0.4g.

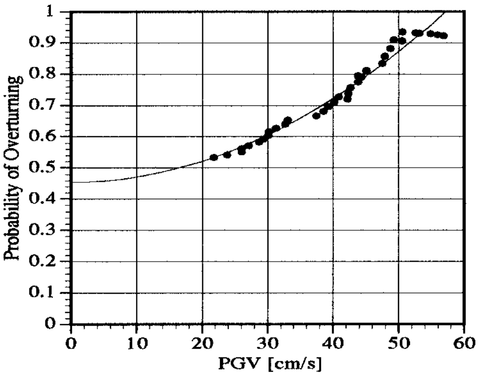

Figure 4. Probability of overturning vs. PGV at PGA=0.7g of a block of h/b=3 and h=60 cm.

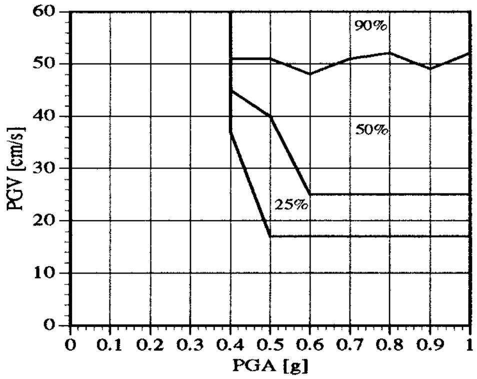

Figure 5. Probability of overturning of a block of h/b=3 and h=60 cm with respect to PGA and PGV.

REFERENCES:

J. Milne, "Experiments in observational seismology" ,*Trans. seism. Soc. Japan* 3, 12-64 (1881).

J. Milne,"Seismic experiments" ,*Trans. seism. Soc. Japan* 8, 1-82 (1885).

G. W. Housner, "The behaviour of inverted pendulum structures during earthquakes", *Bull. seism. Soc. Am.* 53, 403-417 (1963).

C. S. Yim, A. K. Chopra and J. Penzien, "Rocking response of rigid blocks to earthquakes", *Earthquake Engineering and Structural Dynamics* 8, 565-587 (1980).

T. Winkler, K. Meguro and F. Yamazaki, "Response of rigid body assemblies to dynamic excitation",*Earthquake Engineering and Structural Dynamics* 24, 1389-1408 (1995).

M.D. Trifunac and A.G. Brady, "A study on the duration of strong earthquake ground motion", *Bull. seism. Soc. Am.* 65, 581,626 (1975).