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ROCKING RESPONSE OF FREE-STANDING FURNITURES UNDER EARTHQUAKE FLOOR MOTIONS

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Abstract. *Over the last decade the amount of population injured by accident furniture overturning is increased and this trend is expected to continue. Non anchored body motion can be categorized in 6 basic types: rest, slide, rock, slide-rock, free flight and impact. The aim of this research is to analyze through numerical analysis the behavior of a free-standing rigid body during the phase of rocking motion under dynamic load. The model of free body rocking motion was proposed by G. W. Housner in 1963 first. Later a number of alternative models have been developed opportunely change the original assumption in order to and obtain more realistic results.*

In this research different models are compared with numerical simulations, using different excitation input and results are shown in the acceleration-frequency plane. These results confirmed the importance of the geometrical shape of the rigid block and the necessity to individuate the risk factors that can cause overturning phenomena. Nonlinear time history analysis using real earthquake floor motions recorded in a real time monitored building in California are used to simulate the behavior of a furniture located inside a multi-story building. Sensitivity analysis is performed in order to find the optimal location of the furniture inside the building.

The research goal is to establish how to reduce the risk of overturning during an earthquake in real structures and to propose a simple and practical procedure to locate the risk area in the building where slender furniture can overturn. Prevention actions are proposed by changing the shape of the furniture, the friction coefficient or by using some appropriate devices.

1 INTRODUCTION

Although a strong earthquake motion does not always cause severe damage of structures, there may be the possibility that a lot of people are injured by an overturning accident of furniture inside structures. A fundamental topic in the seismic protection is to limit the excessive motion of non-anchored bodies. It can be partitioned in 6 basic conditions: rest, slide, rock, slide-rock, free flight and impact. These motions have been analysed by different authors (Ishiyama, Housner, Shenton, Yim). The purpose of this study is to analyze the behavior of a rigid body under different geometric pulse.

As demonstrated by the analysis, after the input excitation, a rigid body can have different behaviors depending on the system parameters. In particular we can distinguish if a rigid body starts a rocking motion but it doesn't overturn or if it overturns with distinct modes: by exhibiting one or more impacts, and without exhibiting any impact. The results obtained are shown in the acceleration-frequency plane that can be developed for any geometry, in which there are two main areas: a safe zone where the free-standing block doesn't overturn and the other one where the rigid body overturns whether exhibiting impacts or without exhibiting any impact.

Nonlinear time history analysis using real earthquake floor motions recorded in a real time monitored building in California are used to simulate the behavior of a furniture located inside a multi-story building. Sensitivity analysis is performed in order to find the optimal location of the furniture inside the building. Prevention actions are proposed by changing the shape of the furniture, the friction coefficient or by using some appropriate devices.

2 ROCKING RESPONSE OF FREE-STANDING BLOCK

Consider the model shown in Figure 1, which can oscillate about the centres of rotation O and O' when it is set to rocking. Its center of gravity coincides with the geometric center, which is at a distance R from any corner. The angle α of the block is given by $tan(\alpha) = b/h$.

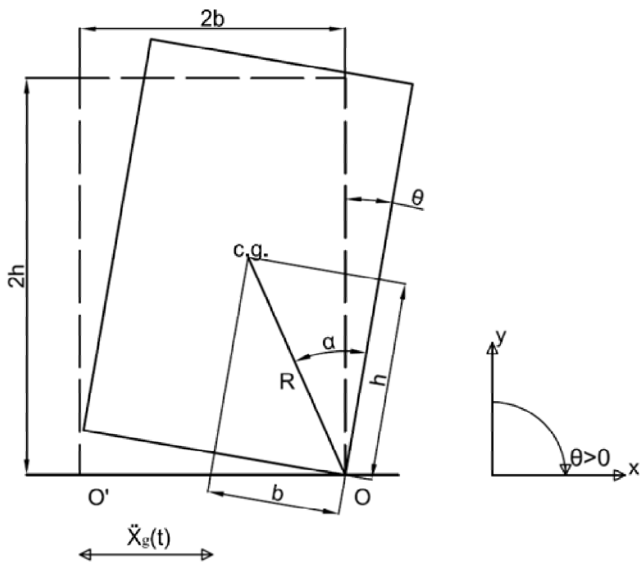

Figure 1 : Schematic of rocking block

Depending on the value of the ground acceleration and the coefficient of friction μ, the block may translate with the ground; enter in a rocking motion or a sliding motion. A necessary condition for the block to enter in a rocking motion is $\mu > b/h$ (Aslam et al. 1980, Scalia and Sumbatyan 1996). The possibility for a block to slide during the rocking motion has been investigated by Zhu and Soong (1997), and Pompei et al. (1998). In this study, it is assumed that the coefficient of friction between the block and its base is sufficiently large to prevent sliding at any instant in the rocking motion.

Under a positive horizontal ground acceleration, $\ddot{u}_g$, the block will initially rotate with a negative rotation, $\theta<0$, and, if it does not overturn, it will eventually assume a positive rotation and so forth. Assuming zero vertical base acceleration ($\ddot{v}_g(t) = 0$), the equations of motion are

$$I_0\ddot{\theta} + mgR\sin(-\alpha-\theta) = -m\ddot{u}_g R\cos(-\alpha-\theta) \qquad \theta<0 \tag{1}$$

and

$$I_0\ddot{\theta} + mgR\sin(\alpha-\theta) = -m\ddot{u}_g R\cos(\alpha-\theta) \qquad \theta>0 \tag{2}$$

Where, for rectangular blocks, can be assumed:

$$I_0 = \frac{4}{3}mR^2 \tag{3}$$

The equations (1) and (2) can be expressed in the compact form

$$\ddot{\theta}(t) = -p^2\left\{\sin\left(\alpha\, sgn\left[\theta(t)\right] - \theta(t)\right) + \frac{\ddot{u}_g}{g}\cos(\alpha\, sgn\left[\theta(t)\right] - \theta(t))\right\} \tag{4}$$

Where

$$p = \sqrt{\frac{3g}{4R}} \tag{5}$$

is a quantity with units in rad/sec.

The oscillation frequency of a rigid block under free vibration is not constant, since it strongly depends on the vibration amplitude (Housner, 1963). Nevertheless, the quantity p is a measure of the dynamic characteristics of the block.

When the block is rocking, it is assumed that the rotation continues smoothly from point O to O' and there is no loss of energy during the rocking motion.

Considering the non linear nature of the problem, for evaluating the various overturning boundaries conditions, equation (4) must be rewritten in a system:

$$\{y(t)\} = \begin{Bmatrix} \theta(t) \\ \dot{\theta}(t) \end{Bmatrix} \tag{6}$$

and the time-derivate vector is

$$f(t) = \{\dot{y}(t)\} = \begin{Bmatrix} \dot{\theta}(t) \\ -p^2\left[\sin\left[\alpha\, sgn[\theta(t)] - \theta(t)\right] + \frac{\ddot{u}_g(t)}{g}\cos\left[\alpha\, sgn[\theta(t)] - \theta(t)\right]\right] \end{Bmatrix} \tag{7}$$

This system can be solved by a numerical integration. One way for performing this integration is to use the standard Ordinary Differential Equation (ODE45) solver available in

MATLAB®, therefore equation (7) was implemented in Matlab, and results found for a given geometry have been shown in the acceleration-frequency plane.

The results are functions of the geometrical shape of the rigid body, in fact it determines the dynamic characteristics p and the angle α which can be considered the limit not to be exceeded to prevent overturning. The ground accelerations are expressed by $\ddot{u}_g$. It can be a real accelerogram or a geometrical pulse creates to simulate the behaviour of the rigid body.

The results obtained shown the variation of the position of the center of gravity, and consequently the variation of the angle θ. During this phase the rocking response is determined by the ratio between the angle θ and angle α. If the ratio is smaller than *1* the rigid body is in a condition of rocking but if the ratio becomes bigger than *1,* the centre of gravity is out of the base of the rigid body, consequently the equilibrium is not satisfied and the object overturns

This type of problem is independent from the mass of the rigid body (the mass m is present in all the terms of equation (1) and (2), and consequently results are equally valid for each rigid body with this particular geometry).

The geometry of the rigid body is very important. In fact, a slender body will have more chances to overturn than a stubby one. This statement is justified by the position of the center of gravity. If the rigid body has a small base and is tall, the center of gravity will have a larger lever arm when it will be subjected to dynamic actions, therefore the possibility of overturning will be more.

3 ROCKING RESPONSE UNDER GEOMETRICAL PULSE

The analysis presented in this section focuses on the overturning potential of some geometrical pulse used to simulate the ground acceleration.

This problem is governed by three major variables: the geometric nature of the system, the acceleration and the frequency of the input. The behavior of a free standing body can be defined after setting these variables.

Once it has been fixed the geometry of the rigid body the acceleration-frequency plane is the most convenient way to show the results. This plane represents all the waves that have been used in the simulation of the behavior of the rigid body. If a specific acceleration and a given frequency will cause the overturning of the rigid body an appropriate sign on the plane will mark this event. The collection of all these accelerations and frequencies that cause the overturning will form the non-secure area of the acceleration-frequency plane. In fact, a line will be the boundary that divides the safe area from the unsafe one.

In order to obtain results is necessary to determine the geometry of the problem. We consider a slender block, then can be assumed $\alpha=0.25$ *rad*. This means that the value of the measure of the dynamic characteristics of the block is $p = 2.14\ rad/s$.

Then the other two variables (acceleration and frequency) that govern the system are ranged and results are summarized in the acceleration-frequency plane.

3.1 One-sine Pulse

The ground acceleration used for this analysis is represented by a sine wave like the one in Figure 2:

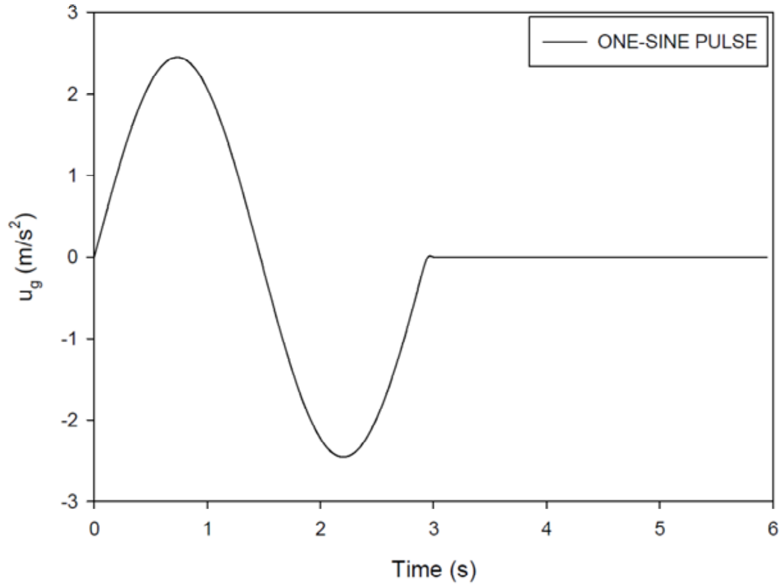

Figure 2 : Ground acceleration one sine pulse

It can be expressed by the following expression:

$$\ddot{u}_g\left(t\right)=a_p\sin\left(\omega_p t\right) \tag{8}$$

Where a_p is responsible of the maximum acceleration while ω_p is the frequency of the input; changing these terms one can explore the whole acceleration-frequency plane.

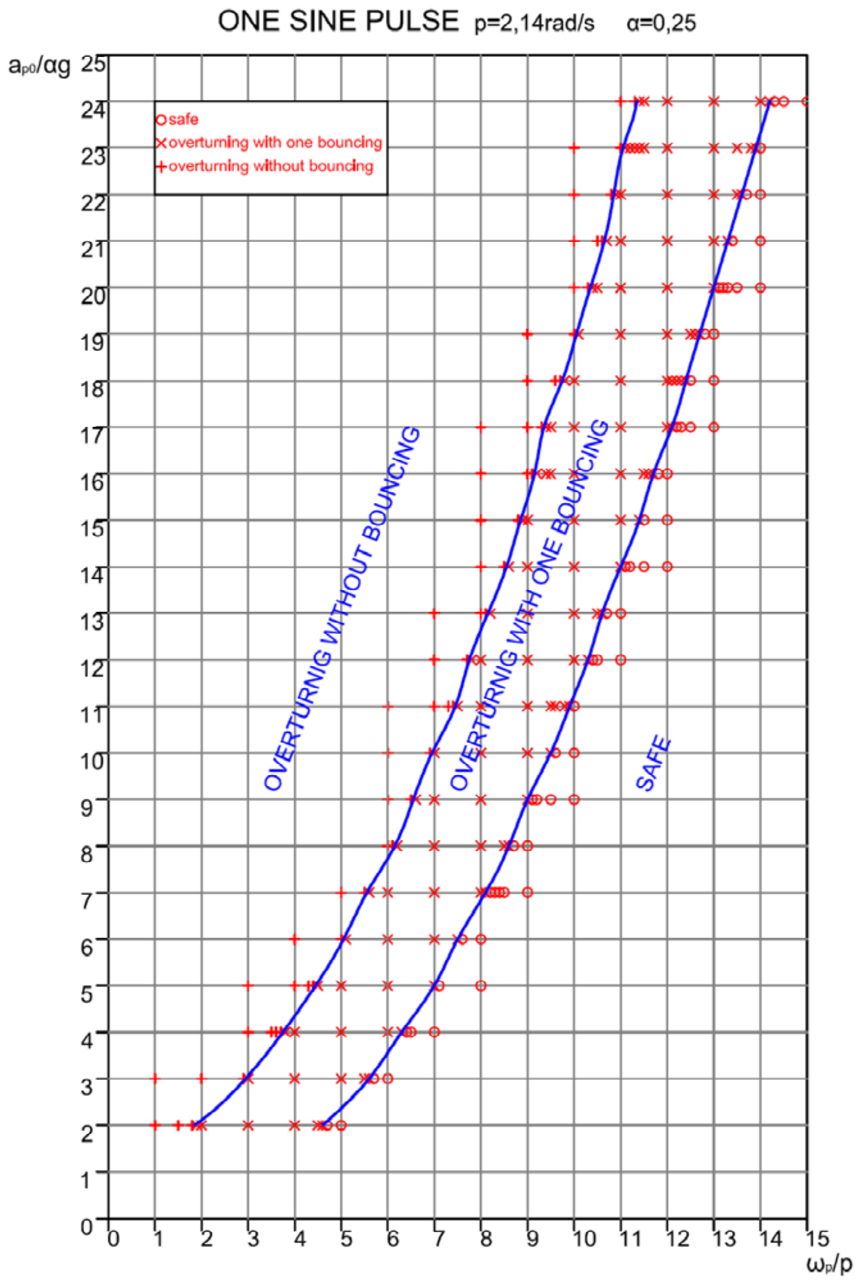

Figure 3 : Acceleration-frequency plane for one-sine pulse.

The results obtained can be grouped into several classes: (i) overturning without bouncing, (ii) overturning with one bouncing, (iii) no overturning.

Overturning without bouncing: in this case the input doesn't enable the rocking motion of the rigid body and the absolute value of the ratio θ/α quickly becomes greater than 1. This means that the rigid body overturns because the equilibrium is not satisfied. A cross is placed in the acceleration-frequency plane where overturning occurs.

Overturning with bouncing: in this case rigid body bounces on a vertex then changes direction of motion and overturns on the other side. This behavior occurs in a specific area of the acceleration-frequency plane, between the previous zones where the reversal occurs and a safe zone where the rigid body doesn't overturn.

No overturning: in this case the rigid body starts a rocking motion and the absolute value of the ratio θ/α remains always less than one, therefore the rigid body does not overturn. It happens in the third main area of the acceleration-frequency plane. This behavior is represented in the plane by a little circle.

3.2 One-cosine Pulse

The ground acceleration used for this analysis is represented by a sine wave like the one in Figure 4:

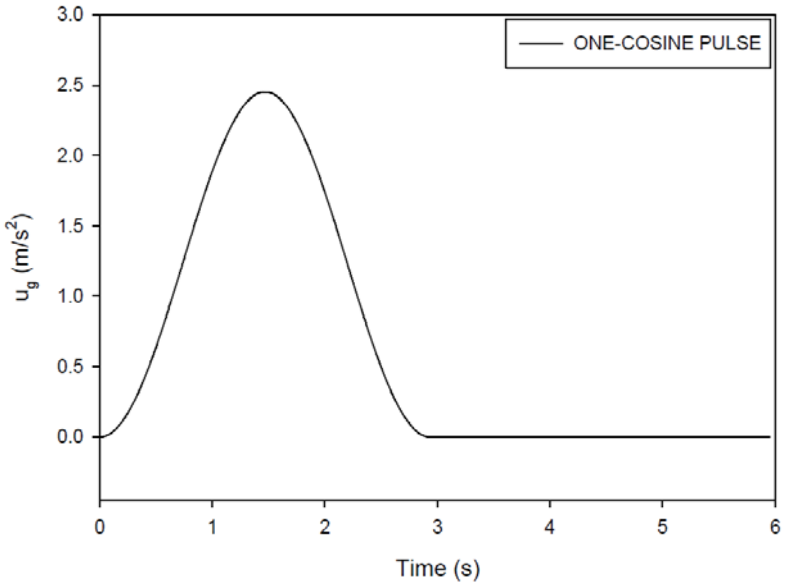

Figure 4: Ground acceleration one sine pulse.

It can be expressed by the following expression:

$$\ddot{u}_g\left(t\right)=\left(\left(a_p-a_p\cos\cos\left(\omega_p t\right)\right)/2\right) \quad (9)$$

The results obtained with this input can be grouped into two classes: overturning without bouncing and no overturning.

The safe area of the acceleration-frequency plane is smaller than the previous case and one can notice the absence of overturning with bouncing this time.

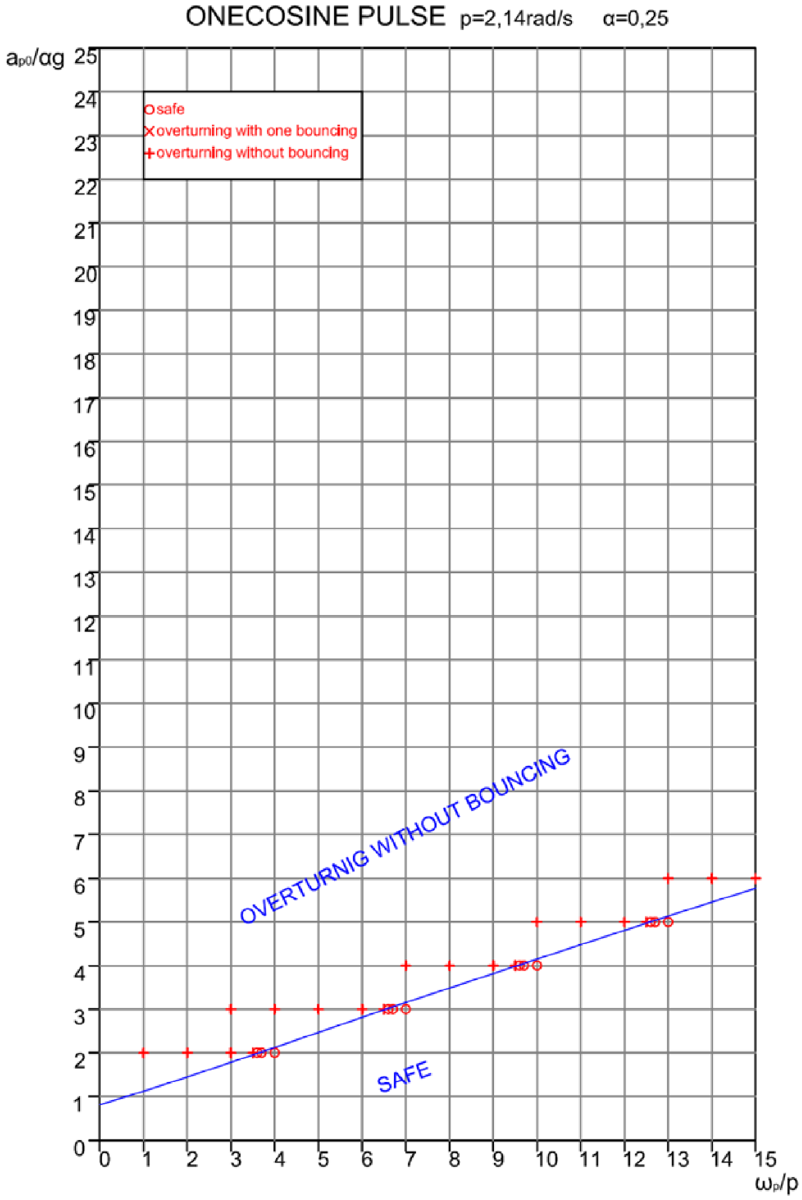

Figure 5: Ground acceleration one cosine pulse.

3.3 Half-sine Pulse

The ground acceleration used for this analysis is represented by a sine wave like the one in Figure 6:

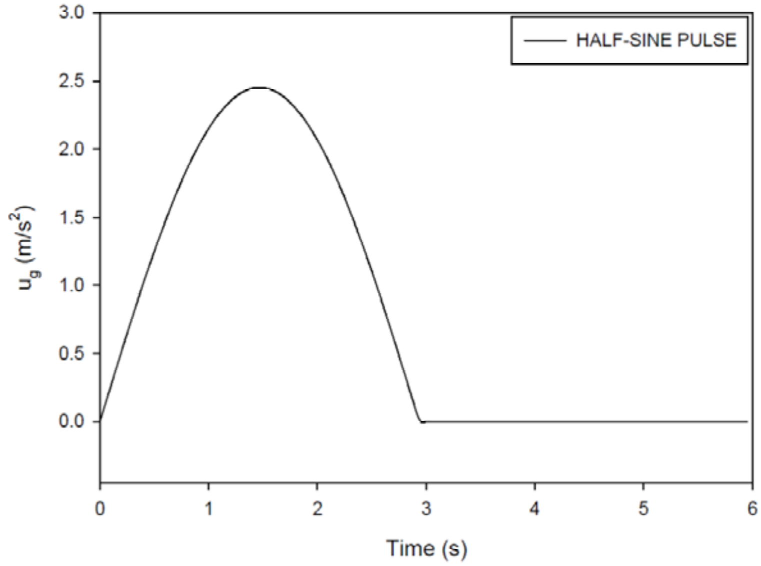

Figure 6: Ground acceleration half sine pulse.

It can be expressed by the following expression:

$$\ddot{u}_g(t) = a_p \sin\left(\left(\omega_p t\right)/2\right) \tag{10}$$

The results obtained with this input can be grouped into two classes: overturning without bouncing and no overturning.

The results obtained are very similar to the previous one obtained for the cosine pulse, but the safe-area is slightly smaller than the previous.

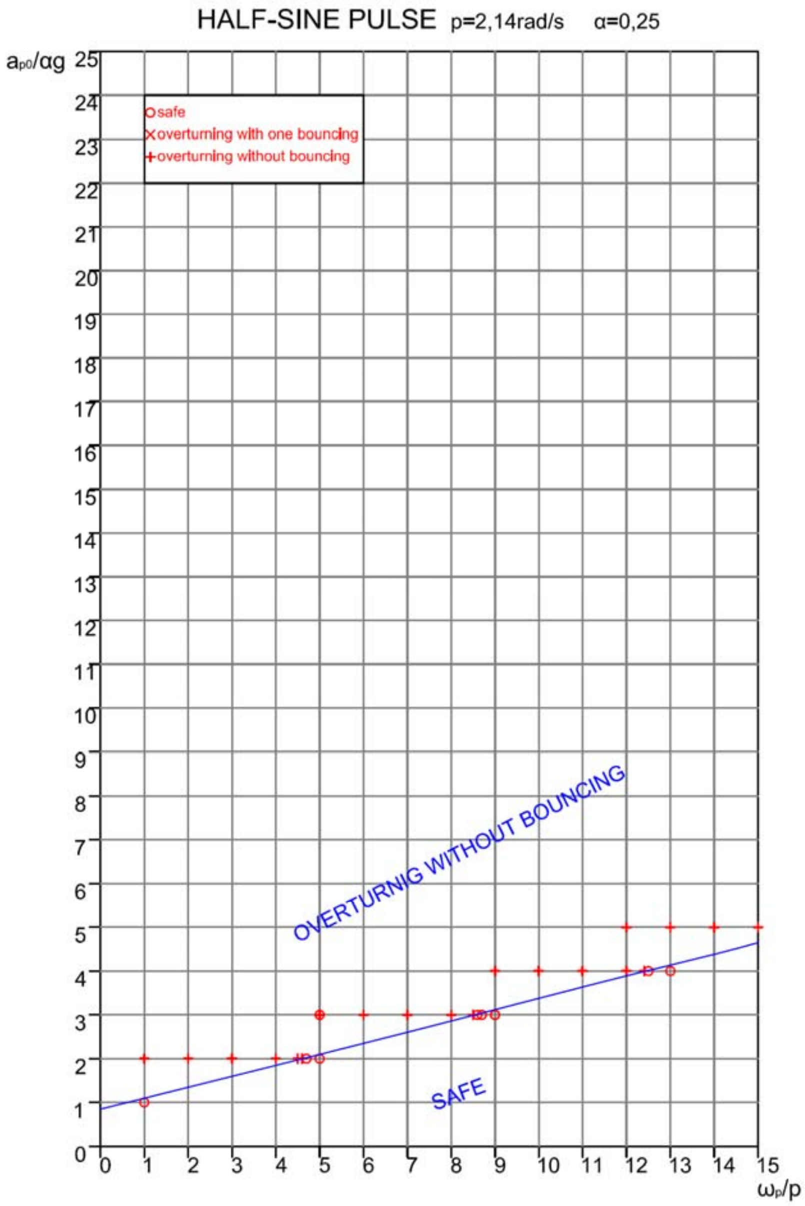

Figure 7: Ground acceleration half-sine pulse.

4 CASE STUDY: TYPICAL STEEL BUILDING IN CALIFORNIA

In this section the overturning potential of one piece of furniture is calculated with real floor acceleration and considering a common piece of furniture.

4.1 Floor motion data

The following table lists real time monitored buildings in California. The geometry of these structures is very different, but they are all made of stainless, they have different floor shape and different number of story. For every building some sensors have been placed in specific place at different height of the structure and with different orientation. Every sensor during a seismic event has recorded the floor acceleration. The total number of floor motion used for the following analysis is 436, some records were discarded because the signal was not clean.

Table-1 Floor motion data

ID	Station	No. of Stories	Height (in.)	Earthquake	PGA (g) Transverse	PGA (g) Longitudinal
001	Pasadena	12	2016	Northridge 17Jan1994	0.135	0.234
002	Burbank	6	990	Whittier87	0.17	0.23
003	San Jose	3	594	LomaPrieta 17Oct1989	0.18	0.2
004	Palm Springs	4	954	PalmSprings86	0.16	0.19
005	South San Francisco	4	726	LomaPrieta 17Oct1989	0.16	0.14
006	Richmond	3	554	LomaPrieta 17Oct1989	0.11	0.08
007	San Jose	13	2527	LomaPrieta 17Oct1989	0.087	0.098
008	San Bernardino	3	496	Landers92	0.11	0.08
009	Burbank	6	990	SierraMadre91	0.11	0.12
010	San Rafael	5	1110	Bolinas99	0.107	0.082
011	Pasadena	12	2016	WhittierNarrows 16Mar2010	0.045	0.11
012	San Bernardino	3	496	San Bernardino 08Jan2009	0.1	0.08
013	San Bernardino	9	1411	Landers92	0.068	0.088
014	Pasadena	12	2314	Northridge 17Jan1994		
015	Pasadena	12	2016	ChinoHills 29Jul2008	0.08	0.06
016	San Bernardino	5	828	Northridge 17Jan1994	0.046	0.057
017	Redlands	7	1253	Landers92	0.06	0.07
018	San Bernardino	5	828	Landers92	0.08	0.08
019	Lancaster	5	942	Landers92	0.08	0.05
020	Chatsworth	2	482	ChinoHills 29Jul2008	0.07	0.04
021	Long Beach	7	1248	Whittier87	0.07	0.04
022	Lancaster	5	942	Landers92	0.055	0.07
023	San Bernardino	5	828	BigBear92	0.06	0.07
024	Los Angeles	32	4214	ChinoHills 29Jul2008	0.065	0.06
025	Long Beach	15	3456	Whittier87	0.055	0.041
026	Long Beach	15	3456	Inglewood 17May2009	0.059	0.043
027	San Bernardino	3	496	ChinoHills 29Jul2008	0.052	0.047
028	Chatsworth	2	482	Chatsworth 09Aug2007	0.04	0.046
029	San Jose	13	2527	MorganHill84	0.039	0.036
030	San Jose	3	594	AlumRock 30Oct2007	0.034	0.027
031	Palm Springs	4	954	Calexico 04Apr2010	0.04	0.02
032	San Bernardino	5	828	ChinoHills 29Jul2008	0.0265	0.036
033	San Bernardino	3	496	LakeElsinore 02Sep2007	0.036	0.031
034	San Diego	22	3804	Calexico 04Apr2010	0.034	0.026
035	Palm Springs	4	954	BorregoSprings 07Jul2010	0.03	0.03
036	Los Angeles	32	4214	WhittierNarrows 16Mar2010	0.028	0.033
037	Redlands	7	1253	Redlands 13Feb2010	0.0255	0.026
038	San Bernardino	3	496	Whittier87	0.029	0.024
039	South San Francisco	4	726	MorganHill84	0.03	0.02
040	Burbank	6	990	ChinoHills 29Jul2008	0.028	0.029
041	San Bernardino	5	828	BigBearCity 22Feb2003	0.0125	0.023

042	San Bernardino	3	496	Calexico 04Apr2010	0.0221	0.0179
043	Long Beach	15	3456	ChinoHills 29Jul2008	0.013	0.021
044	San Bernardino	3	496	BorregoSprings 07Jul2010	0.0179	0.0169
045	Lancaster	5	942	BigBearCity 22Feb2003	0.009	0.008
046	San Diego	22	3804	BorregoSprings 07Jul2010	0.0155	0.0157
047	Los Angeles	32	4214	Inglewood 17May2009	0.008	0.0155
048	Gilroy	2	372	San Martin 15Jun2006	0.016	0.012
049	Richmond	3	554	Piedmont 20Jul2007	0.015	0.013
050	Redlands	7	1253	Calexico 04Apr2010	0.0112	0.0125

4.2 Geometrical dimension of furniture

For the analysis we can consider a piece of furniture like the one shown in the following figure with the following characteristic:

- Width = 0,91 m
- Depth = 0,54 m
- Height = 1,90 m

Obviously the risk of overturning is higher in the shortest side of the furniture.

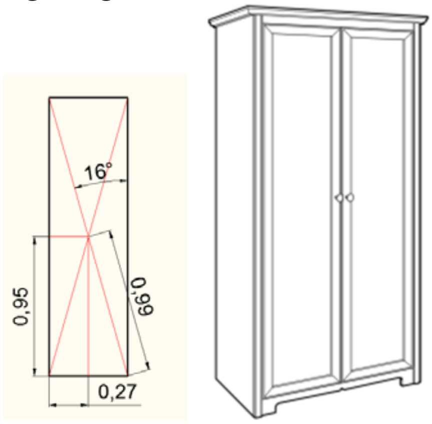

Figure 8 : Geometrical shape of the piece of the furniture.

4.3 Overturning risk

4.3.1. Kaneko risk estimation

Kaneko in 2004 proposed a simplified formula to estimate the risks of the overturning of furniture:

$$R = \begin{cases} \alpha \cdot \phi\left(\left(\ln Acc_f - \lambda_A\right)/\zeta_A\right), F_f \le F_b \\ \alpha \cdot \phi\left(\left(\ln Vel_f - \lambda_V\right)/\zeta_V\right), F_f > F_b \end{cases}$$
$$\lambda_A = \ln\left(\left(B/H\right) g \cdot \left(1 + B/H\right)\right) \tag{11}$$
$$\lambda_V = \ln\left(10B/\sqrt{H} \cdot \left(1 + B/H\right)^{2.5}\right)$$

Where Acc_f [cm/sec^2] is the maximum acceleration and Vel_f [cm/sec] is the maximum velocity floor response, ϕ is the normal distribution function with mean value λ_A or λ_V and standard deviation ζ_A or ζ_V, which is assumed to be 0.2 or 0.3 for an individual piece of furniture. H [cm] and B [cm] are the height and the depth of furniture, g is the acceleration of gravity, F_f [Hz] is the equivalent frequency of floor, F_b [Hz] is the boundary frequency of furniture given by

$$F_f = Acc_f / \left(2\pi Vel_f\right)$$
$$F_b = 15.6 / \sqrt{H} \cdot \left(1 + B / H\right)^{-1.5} \quad (12)$$

α is the slide resistant coefficient which ranges from 0 to 1and is determinate by considering the ratio B/H and the friction coefficient between floor and furniture. In this study, it is assumed that the coefficient of friction between the block and its base is sufficiently large to prevent sliding at any instant in the rocking motion, therefore α=1.

The results obtained from the equation (11) are a measure of the risk of overturning. If the value of R is bigger than 0,7 then the risk will be very high.

The equation (11) has been implemented on matlab in order to estimate the overturning risk for the signals recorded in the considerate building.

The results obtained are shown in Figure 9, and show that the risk of overturning is very high in only three buildings. These buildings are the station San Jose during the earthquake of Lomapietra (17Oct1989) ID 003; the station Palm Springs ID 004 during the earthquake PalmSprings86 and the station South San Francisco ID 005 during the earthquake of Lomapietra (17Oct1989).

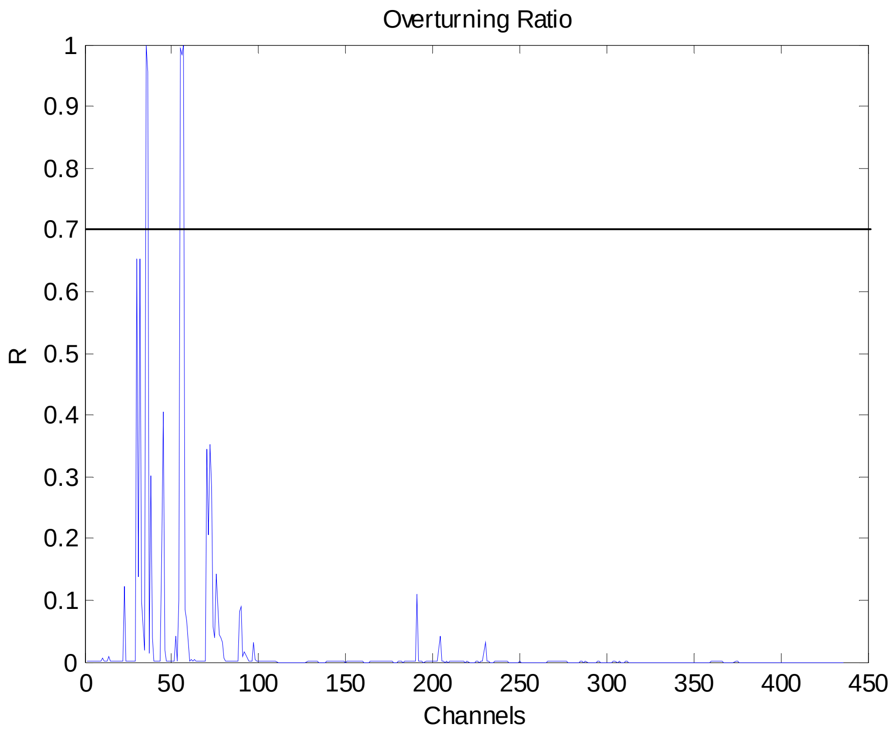

Figure 9 : Overturning risk

The following table summarizes the result obtained with the Kaneko formulation for the three buildings where the risk of overturning is high. In all this building the higher risk is in last floor of the structure, but sometimes the differences between two signals located in the same floor are very large.

Table-2 Overturning risk for Kaneko

ID	story	CHANNEL	R [%]
003	1	ACCCHAN2	0%
	1	ACCCHAN3	0%
	1	ACCCHAN4	0%
	3	ACCCHAN5	65%
	3	ACCCHAN6	14%
	3	ACCCHAN7	65%
	4	ACCCHAN8	10%
	4	ACCCHAN9	2%
	4	ACCCHAN10	100%
004	5	ACCCHAN2	96%
	5	ACCCHAN3	1%
	5	ACCCHAN4	30%
	3	ACCCHAN5	4%
	3	ACCCHAN6	0%
	2	ACCCHAN7	0%
	2	ACCCHAN8	0%
	5	ACCCHAN10	18%
	3	ACCCHAN11	41%
	2	ACCCHAN12	2%
005	1	ACCCHAN4	0%
	1	ACCCHAN5	0%
	2	ACCCHAN6	4%
	2	ACCCHAN7	0%
	2	ACCCHAN8	10%
	5	ACCCHAN9	99%
	5	ACCCHAN10	98%
	5	ACCCHAN11	100%

For example, the results obtained for the record 003 shows a strange conduct in the last floor because for one signal the risk of overturning is very high while for the other two signals on the same floor the risk is negligible. Even if the accelerations of the floor of the structure are different in different point where the signals are recorded these differences are too marked for a single floor response. The same consideration can be done for the building 004 while for the building 005 all the signals on the last floor show high risk of overturning phenomena.

4.3.2. Housner risk estimation

A safety factor for the overturning phenomena has been evaluated also with the Housner formulation Equation(7), considering the floor time history and the same piece of furniture used with Kaneko. This kind of analysis is very expensive in terms of calculation time, in fact for every channel is necessary to solve the differential equation and the computing time can last for several hours. For this reason the analysis has been done only with the three buildings that have shown overturning phenomena with the Kaneko formulation.

The results obtained are shown in the Table 3.

Table 3 : Overturning risk for Housner formulation

ID	story	CHANNEL	[%]
003	1	ACCCHAN2	29%
	1	ACCCHAN3	37%
	1	ACCCHAN4	36%
	3	ACCCHAN5	48%
	3	ACCCHAN6	53%
	3	ACCCHAN7	71%
	4	ACCCHAN8	83%
	4	ACCCHAN9	100%
	4	ACCCHAN10	99%
004	5	ACCCHAN2	100%
	5	ACCCHAN3	100%
	5	ACCCHAN4	71%
	3	ACCCHAN5	77%
	3	ACCCHAN6	59%
	2	ACCCHAN7	37%
	2	ACCCHAN8	40%
	5	ACCCHAN10	100%
	3	ACCCHAN11	77%
	2	ACCCHAN12	56%
005	1	ACCCHAN4	42%
	1	ACCCHAN5	45%
	2	ACCCHAN6	59%
	2	ACCCHAN7	50%
	2	ACCCHAN8	71%
	5	ACCCHAN9	100%
	5	ACCCHAN10	77%
	5	ACCCHAN11	100%

With this model the risk of overturning phenomena within the same floor does not exhibit excessive difference. One can notice higher possibility of overturning in the fourth floor of the building 003 as well as on the fifth floor of the building 004.

This analysis however show higher risk of overturning phenomena compared to the previous one.

5 PROPOSED FORMULATION

The followings formulas have been developed to avoid long calculation times. They have a structure similar to the Kaneko formula but with some new coefficients and some new parameters minimize the differences between the two methods. Therefore the aim of this formula is to avoid the excessive differences between signals on the same floor.

The proposed formula is:

$$OR = \phi\left(\left(\ln Acc_f - \lambda_A\right)/X_1\right) + X_2 \cdot T_1 \cdot \left(\frac{Acc_f}{Vel_f}\right) + X_3 \cdot \left(\frac{H_m}{Dis_f}\right) \cdot \left(B/H\right) \tag{13}$$

Where Acc_f [cm/sec^2] is the maximum acceleration and Vel_f [cm/sec] is the maximum velocity floor response and Dis_f [cm] is the maximum displacement floor response. ϕ is the normal distribution function with mean value λ_A and standard deviation X_1. H [cm] and B [cm] are the height and the depth of furniture. H_m expresses the height from the ground where the furniture is located.

T_1 is the main period of the structure calculate with the approximate formulas proposed by the Italian NTC2008 – Norme tecniche per le costruzioni – D.M. 14 gennaio 2008.

$$T_1 = C_1 \cdot H^{3/4} \tag{14}$$

Where $C_1$is a constant equals to 0,085 for steel frame building and H is the height in meter of the structure.

The coefficient: X_1, X_2, X_3 have been evaluated minimizing the differences between the results of the three building considering only the signals in the last floor of every structure.

X_1 = 0.1104
X_2 = 0.0141
X_3 = -0.0890

The results obtained are shown in the following table:

Table 4 Overturning risk for proposed formulation

ID	story	CHANNEL	[%]
003	1	ACCCHAN2	11%
	1	ACCCHAN3	8%
	1	ACCCHAN4	10%
	3	ACCCHAN5	80%
	3	ACCCHAN6	9%
	3	ACCCHAN7	81%
	4	ACCCHAN8	100%
	4	ACCCHAN9	95%
	4	ACCCHAN10	100%
004	5	ACCCHAN2	100%
	5	ACCCHAN3	98%
	5	ACCCHAN4	13%
	3	ACCCHAN5	6%
	3	ACCCHAN6	7%
	2	ACCCHAN7	10%
	2	ACCCHAN8	10%
	5	ACCCHAN10	100%
	3	ACCCHAN11	41%
	2	ACCCHAN12	9%
005	1	ACCCHAN4	6%
	1	ACCCHAN5	9%
	2	ACCCHAN6	6%
	2	ACCCHAN7	7%
	2	ACCCHAN8	8%
	5	ACCCHAN9	100%
	5	ACCCHAN10	100%
	5	ACCCHAN11	100%

The number of overturning phenomena evaluated with this formula is consistent with the previous one and the behaviour of furniture located in the same plane seems to be improved, as shown in the following figure that summarize all the signal.

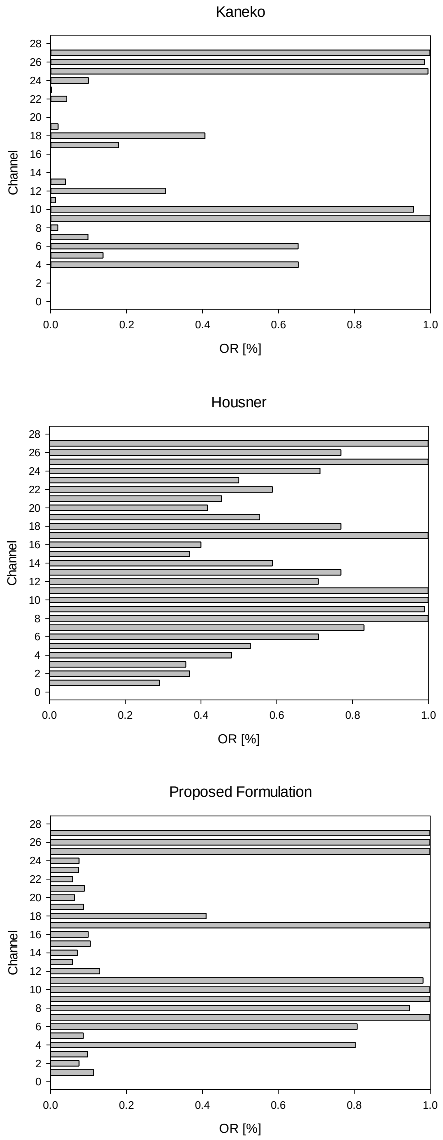

Figure 10 : Overturning ratio for the different formulation

6 CONCLUDING REMARKS

The aim of this study is to establish an easy way to locate the area for overturning risk inside a generic building. The problem is complex but the proposed formulas provide an important support to establish the floor on which are greater the chances of a reversal.

As shown in the Figure 10, all the results clearly indicate that there is the possibility of overturning phenomena in these buildings for some determinate acceleration value e specific furniture geometry. The proposed formulation has the main benefit of the two method used in this research, it is easy to use and the results are homogeneous in specific floor of the structure.

Developments of this research are now directed to give a bigger importance at the shape of the object. The slenderness of the furniture plays an important role in overturning phenomena, therefore the coefficientsX_1, X_2, X_3 must be re-setting using different geometry of the furniture. For example using a bigger base of the furniture one can reduce the lever arm of the rigid body subjected to dynamic actions, this means that the possibility of overturning phenomena will be smaller.

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