LOSSES OF CONTENTS IN TERMS OF THE USE OF THE STRUCTURE

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ABSTRACT:

A methodology for loss estimation due to rocking response of contents subjected to earthquakes for a specific type of use of the building is presented. The case of a typical medium class apartment or house is presented. We first build a realistic inventory in terms of the use of the building and compute the response of every object to a set of strong ground motions to obtain overturning functions in terms of the ground acceleration (A_{max}) and velocity (V_{max}). Then, for each type of building use, we add all these overturning functions considering the fragility of each object and its relative value with respect to the total amount of contents to obtain an overturning function that represents the loss of contents for each building type. Finally, we obtain analytical expressions that fit these overturning functions so they can be easily used to obtain losses by well known methodologies.

KEYWORDS: Losses, contents, use of building, vulnerability function

1. INTRODUCTION

Due to the lack of statistical data, we need to use probabilistic models in order to estimate losses due to natural causes like earthquakes. This estimation implies the use of vulnerability functions that ideally fit observations, if any, which are usually constructed with analytical approaches and expert's opinions. These vulnerability functions should be built in terms of intensity parameters that make sense and have physical meaning (Czarnecki, 1973; Scholl, 1981; Kustu et al., 1982; ; ATC, 1985; Esteva et al., 1988; Ordaz et al., 2000)

During the last 20 years the computation of building losses has been developing extensively. However, as far as the authors are aware, the computation of losses for contents of buildings has not developed on the same pace. Insurance companies, for instance, are interested in reliable estimation of losses of their portfolio which in some cases may exceed the value of the building itself. One traditional way to asses contents losses is to set a percentage of the losses of the building, commonly 50%; however, one can find many examples where all contents are lost while the structure remains intact, or where the structure collapse and all contents are recovered. It is therefore important to find practical methodologies that yield more accurate estimates for the loss of contents.

In this work a methodology for loss estimation due to rocking response of contents subjected to earthquakes and considering the type of use of the building is presented and the case of a typical medium class apartment is used as example. We show a typical inventory of such dwellings and compute the response of every object to a set of recorded strong ground motions to obtain overturning functions in terms of the ground acceleration ($A_{\max}$) and velocity ($V_{\max}$). We build overturning functions for medium class housing by adding all these overturning functions considering the fragility of each object and its relative value with respect the total amount of contents. Finally, we obtain analytical expressions that fit these overturning functions.

2. METHODOLOGY

We propose the following steps to obtain vulnerability functions for contents in terms of the use of the building:

i) To fulfill an inventory of all contents, including their possible damage during an earthquake; in this work we are interested in those objects that will slide or rock, but it is important to determine the percentage of these objects with respect all contents.
ii) To select or create a family of strong ground motions that will affect the site where the building is located
iii) To estimate the fragility and overturning function for every content
iv) To compute the damage function of each building adding every function of the contents.

3. INVENTORY OF CONTENTS IN TERMS OF THE BUILDINGS USE

Table 1 presents examples of the inventory of a typical medium class house or apartment, where image, dimensions, cost (considered as new), percentage of the cost with respect to the total amount of objects, fragility and number of objects per house are shown.

4. STRONG GROUND MOTIONS

Table 2 shows the strong ground motions used in this work. Selected earthquakes cover a wide range of magnitudes (6<M_w<8.1) and epicentral distances (280<R<530km).

5. VULNERABILITY FOR EACH TYPE OF CONTENT

Vulnerability functions of contents should be taken as a measure of the repair cost. For some type of contents, damage grows gradually with intensity, but others have sudden damage when the overturning occurs. For both cases, the expected value of the damage may be represented as a function of intensity. Santa Cruz et al. (2002) deduced a linear expression for determining the damage of a rectangular block with peak acceleration ($A_{\max}$) and velocity ($V_{\max}$) at its base. In this work we use a similar expression:

$$V_o = \begin{cases} 0, & \text{if} \quad A_{\max} < a_b \text{ and } V_{\max} < v_b \\ \dfrac{A_{\max} - a_b}{a_v - a_b} = \dfrac{V_{\max} - v_b}{v_v - v_b}, & \text{if} \quad a_b \le A_{\max} < a_v \text{ and } v_b \le V_{\max} < v_v \\ 1, & \text{if} \quad A_{\max} > a_v \text{ and } V_{\max} > v_v \end{cases} \tag{5.1}$$

where a_b and v_b are the balance acceleration and velocity, and a_v and v_v are the overturning acceleration and velocity of each block.

Figure 1 shows a typical overturning function where it can be observed that for values smaller than a_b and v_b the body will stand still, for values larger than a_b and v_b the body will rock and when it reaches a_v and v_v the body will overturn. Depending on the fragility of the body this overturning will produce null or total loss, as will be shown later.

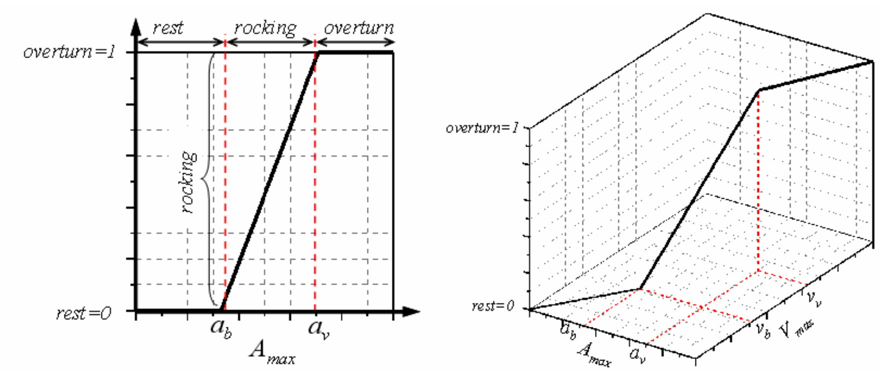
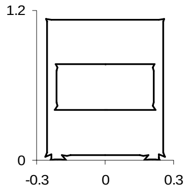
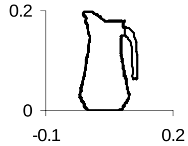
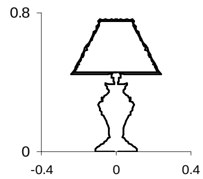
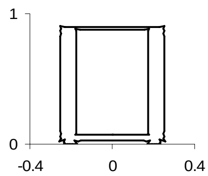
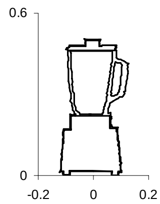
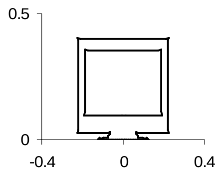
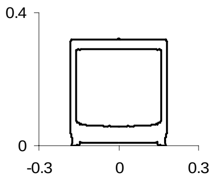
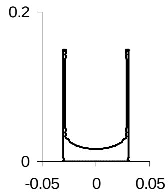
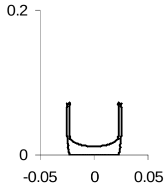
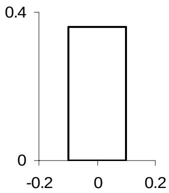
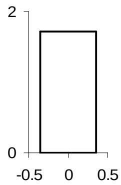
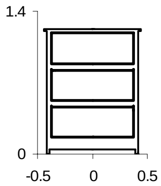
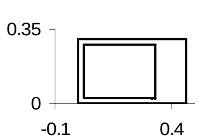
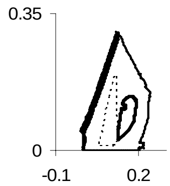
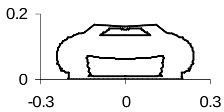
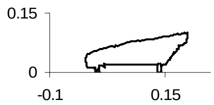
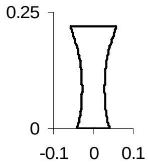


Figure 1 Overturning function in terms of acceleration and velocity

Table 1. Inventory of the contents that may rock in a medium class house or apartment

		stove		jar		lamp
Ammount	1		2		3	
Cost	$2000		$200		$300	
Total cost:	$2000		$400		$900	
% Loss:	1.90		0.47		1.07	
Fragility:	0.8		1.00		1.00	
		washer		blender		monitor
Ammount	1		2		1	
Cost	$2500		$800		$2200	
Total cost:	$2500		$1600		$2200	
% Loss:	2.37		1.52		2.09	
Fragility:	0.8		0.8		0.8	
		Television		big glass		small glass
Ammount	2		6		6	
Cost	$2200		$50		$30	
Total cost:	$4400		$300		$180	
% Loss:	4.18		0.36		0.21	
Fragility:	0.8		1.0		1.0	
		CPU		refrigerator		shelf
Ammount	1		1		2	
Cost	$7300		$4750		$300	
Total costl:	$7300		$4750		$600	
% Loss:	6.93		4.51		0.43	
Fragility:	0.8		0.8		0.6	
		microwaves		iron		stereo
Ammount	1		1		1	
Cost	$700		$450		$400	
Total cost:	$700		$450		$400	
% Loss:	0.66		0.43		0.38	
Fragility:	0.8		0.60		0.8	
		telephone		vase		
Ammount	1		3		Total cost of objects without damage by overturning: $55,145 MXP ~ 5,000 USD Total cost of contents: $84,285 MXP ~ 8,000 USD	
Cost	$250		$70			
Total cost:	$250		$210			
% Loss:	0.18		0.25			
Fragility:	0.6		1.0			

For the computation of ab, we consider that each body stars rocking when the acceleration at its bae is larger than the ratio height/with (Milne, 1885),

$$a_b = g\left(b/h\right) \tag{5.2}$$

To compute v_b, we have scaled each one of the strong ground motions of Table 2 so A_{max} be equal to the acceleration of Eqn. (5.2). Figure 2 presents pairs of values of a_b and v_b (crosses at the bottom) computed for a stove, a vase and a fridge located in an apartment or house in the firm zone of Mexico City. For a given value of a_b, there are many values of v_b; the uncertainties are taken into account as will be shown later.

Table 2. Recorded strong ground motions used in this study

No.	Date	Seismic gap	M	Latitude	Longitude	Depth	Distance-CU	Azimuth-CU	CU	SCT	CD
1	23/08/65	Oax. Este	7.8	16.28	96.02	16	466	135	✓	-	-
2	02/08/68	Oax. Oeste	7.4	16.25	98.08	33	326	160	x	-	-
3	07/06/76	Guerrero	6.4	17.45	100.65	48	292	215	✓	-	-
4	19/03/78	San Marcos	6.4	16.85	99.9	16	285	200	✓	-	-
5	29/11/78	Oaxaca	7.8	16.00	96.69	19	414	140	✓	-	-
6	14/03/79	Petatlán	7.6	17.46	101.46	20	287	230	✓	-	-
7	25/10/81	Michoacán	7.3	17.75	102.25	20	330	237	✓	-	-
8	07/06/82	Ometepec	6.9	16.35	98.37	15	304	165	✓	-	-
9	07/06/82	Ometepec	7.0	16.35	98.37	15	303	165	✓	-	-
10	19/09/85	Michoacán	8.1	18.14	102.71	15	295	255	✓	✓	✓
11	21/09/85	Petatlán	7.6	17.62	101.82	15	318	240	✓	-	✓
12	30/04/86	Michoacán	7.0	18.42	102.99	16	409	255	✓	-	x
13	25/04/89	Ometepec	6.9	16.60	99.40	19	290	185	✓	✓	✓
14	31/05/90	Guerrero	6.1	17.15	100.85	21	304	210	✓	✓	✓
15	15/05/93	Ometepec	6.0	16.47	98.72	20	320	170	x	-	✓
16	24/10/93	Ometepec	6.7	16.50	99.00	19	310	170	✓	✓	✓
17	10/12/94	Petatlán	6.6	18.02	101.56	20	300	170	✓	✓	✓
18	14/09/95	Ometepec	7.3	16.31	98.88	45	320	260	✓	✓	✓
19	09/10/95	Jalisco	8.0	18.85	104.53	27	530	260	x	x	✓
20	15/07/96	Petatlán	6.6	17.40	101.10	20	301	230	✓	x	-
21	03/02/98	Oaxaca	6.3	15.69	96.37	33	509	138	✓	✓	x

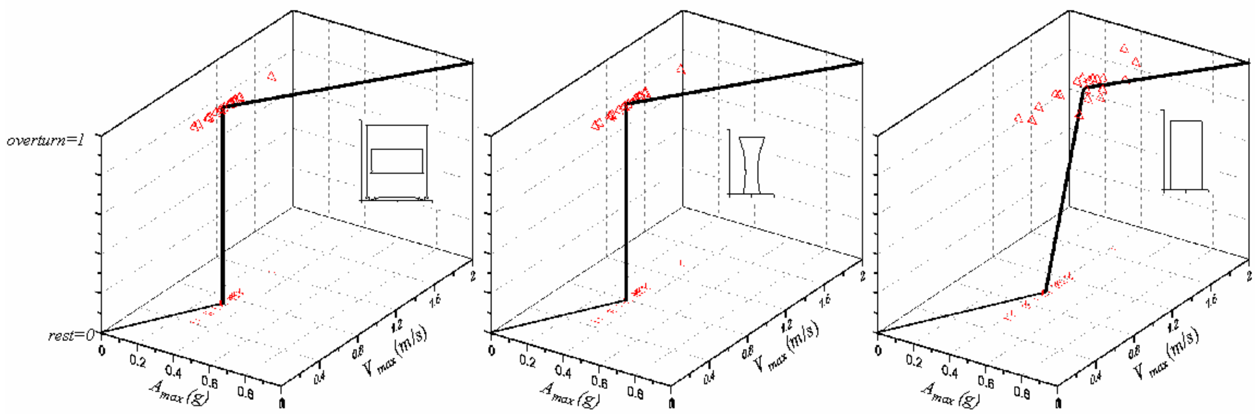


Figure 2 Overturning function of a stove, vase and fridge for an apartment or house located at a firm site

To obtain peak acceleration (a_v) and velocity (v_v) for which each body may overturn, we have followed an interactive procedure. We obtained the dynamic response of each body to a horizontal strong ground motion (Shenton and Jones, 1991; Makris and Roussos, 1998). This implies considering a restitution coefficient and the friction of contact (Milne, 1885; Housner, 1963). The first interaction is carried out scaling the motion so A_{max}=a_b; following interactions are done with increments of 0.05 of acceleration. We stop the process when the body overturns and keep the pairs of a_v and v_v (triangles at the top, Figure 2). Different values of a_v and v_v are due to differences on the characteristics (frequency content, duration, among others) of the scaled strong ground motions used. Table 3 presents the average values of a_b, v_b, a_v and v_v for the stove, vase and fridge; with these average values, we have plotted with solid line the overturning functions of Figure 2.

Table 3. Values of a_b, v_b, a_v and v_v for the stove, vase and fridge shown in Figure 3 for site CU

Identification	a_b (m/s^2)	v_b (m/s)	a_v (m/s^2)	v_v (m/s)
Stove	2.93	0.65	2.93	0.65
Fridge	4.05	0.90	5.15	1.14
Vase	3.27	0.72	3.27	0.72

Figure 3a graphically compares the overturning functions shown in Figure 2 and other two objects (stove, iron, vase, fridge and CPU) where different pairs of a_b-v_b and a_v-v_v (the corners of the overturning functions) can be seen. It can also be appreciated, for instance, that the stove will stand still for any A_{max}<0.25g and V_{max}<0.55 m/s, and that it will overturn with slightly higher values; this is due to the geometry of the fridge since the intensities that produce rocking are very similar to the intensities that produce overturning. The iron, on the contrary, exhibits a wider difference between the rocking and overturning values.

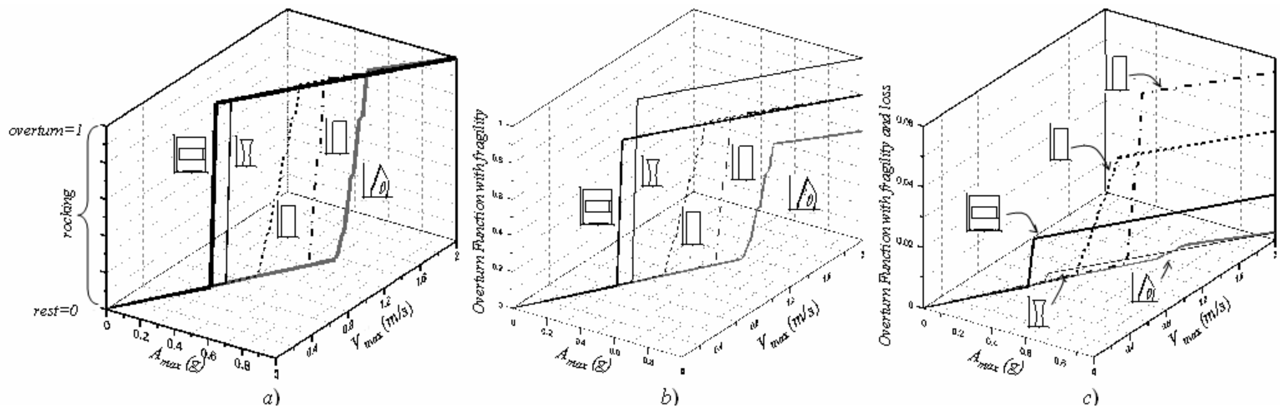


Figure 3 Overturning functions with respect to a_b-v_b and a_v-v_v pairs and for five typical objects of an apartment or a house (stove, iron, vase, fridge and CPU): (a) Shows rest-rocking-overturning for each object, (b) Normalized by fragility and (c) Normalized by fragility and relative loss with respect to total contents of the apartment

5.1. Fragility

Now, let us take into account the fragility of each object since overturning damage maters mainly if the object breaks or get damage. We lack inventories of damage to contents so we have to rely on general information such as that shown by Table 4 that has some examples taken from ISO-1982; D_{max} is the damage expected if the body overturns. It is clear that damage to paper (5%) is much smaller than to Glassware-art (100%). Figure 3b shows the overturning functions of Figure 3a but normalized with respect to Dmax.

Table 4. Examples of fragility of diferent objects (ISO 1982)

Classification	Examples	D_{max} (%)
Null	paper roll, security boxes	5
Not very vulnerable	wooden furniture, food boxes	30
Vulnerable	computers, radios set	80
Very vulnerable	glassware, art, porcelain	100

To take into account the individual contribution of each object to the total value of all contents we normalize the overturning function with respect to its individual value. Figure 3c shows the overturning functions normalized by the fragility (Figure 3b) and by the value of each object shown in Table 1. It can be seen, for instance, that the vase is very vulnerable but its contribution with respect to the total losses is very small; on the other hand, the CPU and the fridge contribute significantly.

6. VULNERABILITY FUNCTION IN TERMS OF THE BUILDING USE

We propose to obtain the vulnerability function as the sum of all overturning functions normalized by fragility and cost. Figure 4 shows the vulnerability function computed for all contents of a typical apartment or house in terms of A_{max} and V_{max}. Since strong ground motions used are those from station at a firm site, this vulnerability function is valid only for firm sites. For lakebed zone the same process may be used but with strong ground motions recorded there.

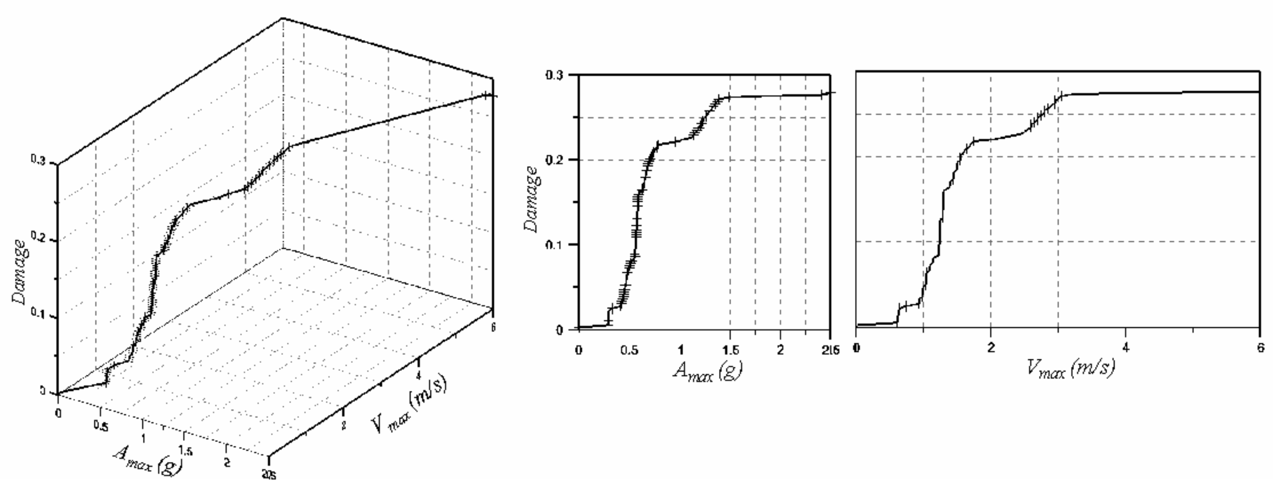


Figure 4 Vulnerability function at a firm site computed for all contents of a typical apartment or house in terms of A_{max} and V_{max}.

The vulnerability function shown in Figure 4 may be used as shown in Figure 4 or one may adjust a functional form so it is easy to be programmed and used in many applications. We propose to use the following form:

$$D = \left(1 - 0.5^{\left(\frac{X}{\beta_1}\right)^{\beta_2}}\right) \cdot \left(\exp\left(-4.08 \cdot Y^2\right)\right) \cdot D_{\max} \tag{6.1}$$

where

$$\left.\begin{aligned} X &= V_{\max} \cdot \cos(-\alpha) - A_{\max} \sin(-\alpha) \\ Y &= V_{\max} \cdot \sin(-\alpha) + A_{\max} \cdot \cos(-\alpha) \end{aligned}\right\} \quad \alpha = \tan^{-1}(\omega) \tag{6.2}$$

where β_1 and β_2 are coefficients from the fit that was carried out for a typical building use, $D_{\max}$ is the maximum damage shown above in this work and is ω a parameter that represents the frequency content of the seismic motion. Table 5 shows these values for three typical uses (medium housing, residential housing and office). Figure 5 shows the vulnerability function of the contents of a medium class housing obtained with Eqn. (6.1).

Table 5. Coefficients for the vulnerability function

Use	β_1	β_2	$D_{\max}$	ω
medium class housing	5.96	4.068	0.278	7.73
residential	4.165	1.529	0.355	7.73
Office	6.071	2.834	0.47	7.73

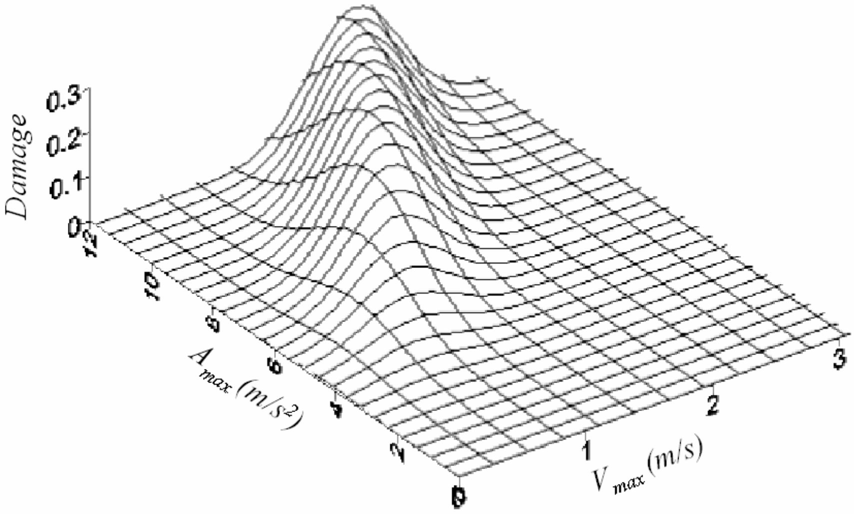


Figure 5 Vulnerability function of the contents of a medium class housing for a firm site in Mexico City

Figure 6 presents a comparison of three vulnerability functions obtained as described in this work. They correspond to medium class housing (solid line), residential housing (continuous line) and office (discontinuous line). It is clear that residential housing is the most vulnerable of all three. For instance, if an earthquake with A_{max}=0.4g y V_{max}=1.0m/s occurs, the damage of contents would be around 20% for medium housing and office use, but for residential housing would be more than twice, almost 45 %.

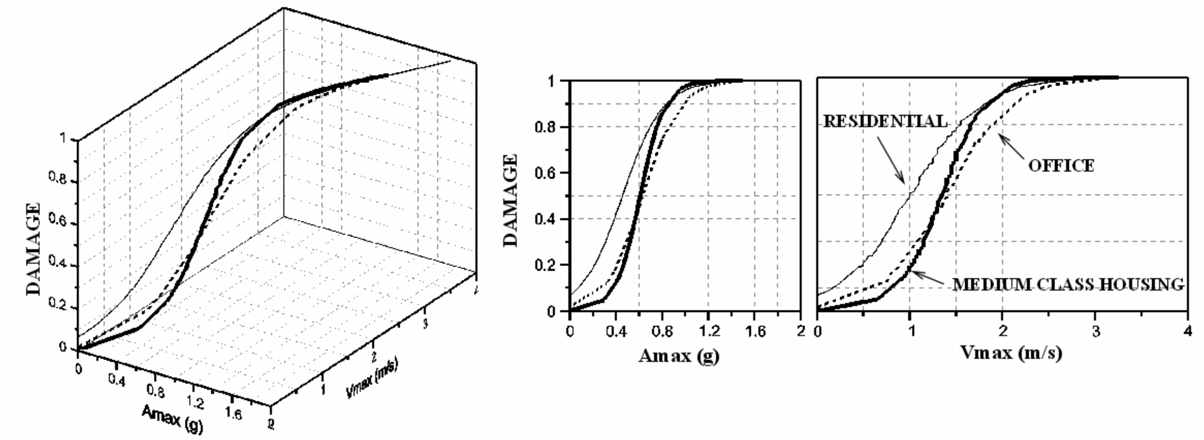


Figure 6 Vulnerability functions of the contents of a medium class housing, residential housing and office

7. CONCLUSION

We present a methodology for loss estimation due to rocking response of contents subjected to earthquakes and considering the type of use of the building. The case of a typical medium class apartment or house is presented. We present analytical expressions so they can be easily used to obtain losses by well known methodologies. This way of obtaining vulnerability functions is very useful with loss estimation methodologies since very little information is needed, only the use of the building.

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