6-17-2019

# Seismic Vulnerability Assessment of Anchored Block Type Contents Due to Sliding and Overturning

Sereen Majdalaweyh
*Clemson University*

Weichiang Pang
*Clemson University*, wpang@clemson.edu

Amir Safiey
*Clemson University*, asafiey@g.clemson.edu

Ershad Ziaei
*Clemson University*

Keivan Rokneddin
*AIG*

***See next page for additional authors***

**Authors**
Sereen Majdalaweyh, Weichiang Pang, Amir Safiey, Ershad Ziaei, Keivan Rokneddin, Mohammad Javanbarg, and Saurabh Prabhu

12th Canadian Conference on Earthquake Engineering
12ème Conférence canadienne du génie parasismique
June 17-20, 2019 – Château Frontenac, Québec, QC.
17-20 juin 2019
CCEE 2019

# Seismic Vulnerability Assessment of Anchored Block Type Contents Due to Sliding and Overturning

Sereen Majdalaweyh[1], Weichiang Pang[2], Amir Safiey[3], Ershad Ziaei[4], Keivan Rokneddin[5], Mohammad Javanbarg[6], and Saurabh Prabhu[7]

[1] Ph.D. Student, Glenn Department of Civil Engineering, Clemson University - Clemson, SC, United States.
[2] Associate Professor, Glenn Department of Civil Engineering, Clemson University - Clemson, SC, United States.
[3] Ph.D. Candidate, Glenn Department of Civil Engineering, Clemson University - Clemson, SC, United States.
[4] Post-Doctoral Fellow, Glenn Department of Civil Engineering, Clemson University - Clemson, SC, United States.
[5] Manager of Earthquake Modeling, Research, and Development, AIG - Philadelphia, PA, United States.
[6] Adjunct Professor, Glenn Department of Civil Engineering, Clemson University, AIG - New York, NY, United States.
[7] Senior Catastrophic Research Analyst, AIG - Greenville, SC, United States.

## ABSTRACT

Damage to contents and nonstructural components is often the main driver of property losses against smaller earthquakes as evidenced by empirical evidence from past events. In the 2014 South Napa earthquake in California, for example, 56% of the affected buildings reported content damage. The primary modes of content damage include sliding, rocking, and overturning. The FEMA P-58 document provides seismic fragility functions for sliding and overturning of unanchored block content types, but no data is provided for anchored components. The ASCE/SEI 7-16 provides stability guidelines for different types of nonstructural components, but falls short of providing recommendations for the contents and furniture. This study investigates the behavior of anchored contents in commercial buildings and explores the impact of anchorage on the economic losses caused by content damage due to earthquake shaking. Anchored contents are generally represented here by rigid blocks with post-tensioned cables. The presented methodology adopts two engineering demand parameters (EDPs), the sliding displacement and the rotation angle of the rigid block, which are estimated by analytically modeling sliding and overturning responses due to ground motions. Their respective fragility functions are subsequently used to quantify the content seismic vulnerability by taking the maximum losses from sliding and overturning failure modes. The vulnerability functions of anchored versus unanchored contents are compared for commercial buildings of two different structural systems: steel and reinforced concrete moment resisting frames. Comparing the anchored and unanchored vulnerability functions reveals that the unanchored contents are more susceptible to damage and losses than the anchored ones. Moreover, numerical simulations show the extent of reduction in vulnerability, in terms of financial losses, for each level of spectral acceleration as the result of anchorage.

Keywords: Block-Type Contents, Sliding, Overturning, Fragility, Seismic Vulnerability Assessment.

## INTRODUCTION

The damage to nonstructural components such as mechanical and electrical equipment, architectural features and movable building contents drives the earthquake losses of modern, code-complying buildings, particularly for low to medium shake intensities. The ATC post-earthquake reconnaissance report following August 24, 2014, Napa Valley earthquake in California ($M_w = 6$) highlights this fact by recording the large contribution from nonstructural components to the overall damage compared to the structural components while 80 buildings out of 134 buildings suffered from nonstructural damage [1]. Content components may slide, rock or overturn in an earthquake event and thus pose a risk to the safety of residents in addition to their potential to drive losses. The only reported fatality was attributed to the shifting of a television set of an office table and fell off the victim's head [1]. Since the majority of earthquakes a region may experience are expected to produce lower levels of shaking intensity, understanding the seismic performance of contents is of substantial value for loss prevention and increasing public safety.

While FEMA P-58 [2] provides a component-based framework for assessing the seismic performance of buildings and presents component fragility and consequence functions, its application to content damage assessment is very limited as it only offers one generic component type with a single damage state which is not paired with any consequence function. Nonetheless, the P-58's component-based framework can be extended to estimate the damage from contents if new fragility and consequence functions are provided [3]. This study aims to develop seismic fragility functions and collect information on damage state consequences for typical content components in commercial buildings. Different studies focused on free-standing type of contents, the sliding and rocking response of free-standing contents to a group of ground motions to obtain the probability of failure with respect to the horizontal peak ground acceleration [4-10], however limited studies focused on the sliding and rocking response of anchored contents [11-12]. In particular, this study focuses on anchored content types which are more frequently found in commercial environments. The presented methodology uses analytical models to develop the fragility functions for freestanding or anchored contents. The fragility functions are subsequently paired with consequence functions to derive vulnerability functions for the targeted content components. The methodology is showcased for two four-story office buildings with steel and reinforced concrete moment frames designed for high seismic region per ASCE 7 (Seismic Design Category = $D_{max}$) [4].

## METHODOLOGY

This study presents the loss estimation analyses at both the content and building levels. At the content level, building contents are modeled as two-dimensional rigid blocks and subjected to 22 pairs of tri-axial, far-field ground motions provided by FEMA P-695 [13]. Nonlinear incremental dynamic analysis (IDA) [14] is adopted for the time history analysis of freestanding and anchored models to determine two content engineering demand parameters ($EDP_c$): the sliding displacement and rotational angle. The damage states for each component are subsequently defined by engineering judgment and used to develop the fragility functions. At the building level, the entire building is modeled as a two-dimensional building archetype subjected to the same far-field ground motions provided by FEMA P-695. Nonlinear dynamic incremental analysis is used for the time history analysis of the building model to determine the building engineering demand parameters ($EDP_B$), where $EDP_B$'s are the peak inter-story drifts, peak inter-story residual drifts or peak floor accelerations. Realizations of $EDP_B$ are then generated to examine the building damage states, and if the building does not collapse in a realization, content losses are estimated using the fragility and consequence functions developed at the content level. The content losses are presented as the ratio of the sum of content losses to the total content value in the building.

### Dynamic model

Building contents are represented as a rigid block (Figure 1). The rigid block has width $b$ and height $h$ with a uniform mass distribution with a center of gravity at the center of geometry and rests on a horizontal surface subjected to both horizontal and vertical ground accelerations $\ddot{x}_g(t)$ and $\ddot{y}_g(t)$, respectively. Two dynamic models are used in this study (i) the freestanding rigid block as shown in Figure 1a and (ii) the anchored rigid block as shown in Figure 1b.

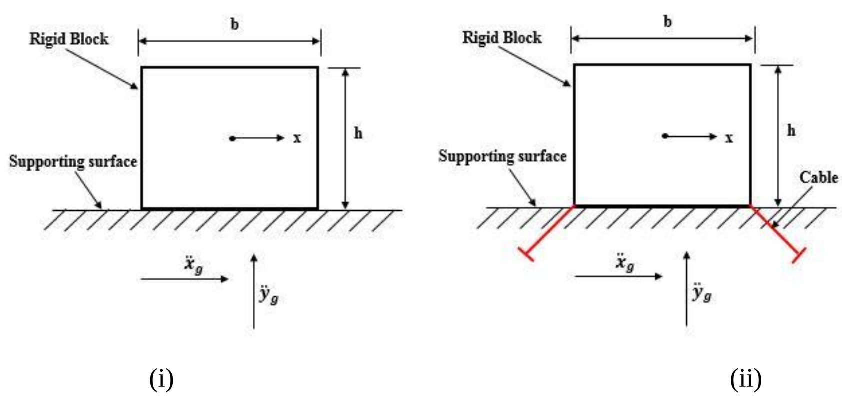



*Figure 1. Rigid block models: (i) Free Standing (ii) Anchored*

### Free-standing rigid block

The nonlinear sliding motion of the free-standing rigid block can be described as [8]:

$$\ddot{x}(t) + \mu\big[g + \ddot{y}_g(t)\big] \cdot sgn[\dot{x}(t)] = -\ddot{x}_g(t) \tag{1}$$

where $\ddot{x}(t)$ and $\dot{x}(t)$ are the acceleration and velocity response of the rigid block due to excitation at the center of the block with respect to the supporting surface. $g$ is the acceleration due to gravity, $\mu$ denotes the friction coefficient, and $sgn[\dot{x}(t)]$ is the signum function:

$$sgn[\dot{x}(t)] = \begin{Bmatrix} +1, & \dot{x}(t) > 0 \\ -1, & \dot{x}(t) < 0 \end{Bmatrix} \tag{2}$$

Sliding will initiate when the horizontal inertial force exceeds the frictional force. The conditions that assumed for the sliding equation of motion in this study are: (1) the kinetic and static friction coefficient are equal. (2) the friction coefficient of the building contents varies with the flooring surface, and the content type and the range for office contents is assumed to be (0.2-0.45). (3) for simplicity, sliding is assumed to be decoupled from the other forms of motion (i.e. jumping, and rocking).

The rocking equation, on the other hand, is formulated as follows [7]:

$$\ddot{\theta}(t) = -p^2\left\{sin[\alpha \cdot sgn[\theta(t)] - \theta(t)]\left(1 + \frac{\ddot{y}_g(t)}{g}\right) + \frac{\ddot{x}_g(t)}{g}cos[\alpha \cdot sgn[\theta(t)] - \theta(t)]\right\} \tag{3}$$

where $\ddot{\theta}(t)$ and $\theta(t)$ are the angular acceleration and the rotation angle of the block, respectively; $\alpha$ is the shape factor which is equal to $tan^{-1}\left(\frac{b}{h}\right)$; $p$ denotes the frequency factor which is equal to $\sqrt{\frac{3g}{4R}}$; and $R = \sqrt{b^2 + h^2}$.

The block starts rocking when the moment produced by the horizontal inertia forces exceeds the moment resulting from the weight of the block and the vertical inertia forces. After initiation of rocking, the block will rock until the rotational angle θ exceeds the shape factor α (i.e., θ/α=>1). In order to take into account the loss of energy due to the rigid block impact to the ground while rocking, the coefficient of restitution is needed; the maximum coefficient of restitution is $r_{max} = \left(1 - \frac{3}{2}sin\,\alpha^2\right)^2$, which multiplied by the angular velocity when it reverses from positive to negative and vice versa.

**Anchored rigid block**

Each rectangular block is anchored with two cables characterized by axial stiffness, initial tension, and elastic-brittle behavior (only at the x-direction). The nonlinear dynamic model for sliding is presented by [11]:

$$\ddot{x}(t) + \mu\big[g(1 + \beta) + \ddot{y}_g(t)\big] \cdot sgn[\dot{x}(t)] + \left(\frac{2\pi}{T_{eq}}\right)^2 x(t) = -\ddot{x}_g(t) \tag{4}$$

The sliding response of the anchored block depends on the strength ratio of the cable ($\beta$) which represents the ratio of the ultimate axial force capacity of the cable to the weight of the block. The sliding response also depends on the equivalent period of the system $T_{eq}$. During a seismic excitation, Eq. (4) remains valid until the cables reach their yielding displacement points, after which they are assumed to break and the block will switch to the free-standing condition which is represented by Eq. (1).

On top of the conditions mentioned for the freestanding sliding block, four additional conditions are considered for the anchored sliding model: (4) the cables are considered to be in tension at all times, (5) the ultimate strength of the cable is equal to its yielding strength, (6) the strength ratio depends on the cable properties and the block weight which, for office contents, is considered to be in range of (0.7-1.0) [11], and (7) the anchored block system is considered to be a rigid system with an equivalent period less than 0.06 seconds [15].

The nonlinear model for rocking of the rigid rectangular block [7] is:

$$\ddot{\theta}(t) = -p^2\left\{sin[\alpha \cdot sgn[\theta(t)] - \theta(t)]\left(1 + \frac{\ddot{y}_g(t)}{g}\right) + \frac{\ddot{x}_g(t)}{g}\cos[\alpha \cdot sgn[\theta(t)] - \theta(t)] + \frac{3\beta\sin\alpha^2}{q}sin\theta(t)\right\} \tag{5}$$

where, $q = \frac{2b\theta_y p^2}{g}$ is the influence parameter and $\theta_y$ is the yielding rotational angle for the cable. This equation remains valid until the cable reaches its yielding displacement under earthquake excitation, after which the anchorage breaks and the motion follows Eq. (3), i.e. free rocking.

These nonlinear second order ordinary differential equations are solved using the Ode45 solver in MATLAB [16] to determine the sliding and rocking response of contents, sliding displacement *x*, and rotational angle *θ*.

## FRAGILITY FUNCTION AND RELATIVE REPLACEMENT COST

Fragility functions (curves) describe the probability that a component exceeds a certain damage state at different shaking intensity levels. The damage states are often defined by Engineering Demand Parameters (EDP), which in turn depend on the shaking intensity and component properties. There are three general methods to develop fragility functions: Empirical, Analytical, and Expert opinion [2]. In lack of sufficient test data to derive the fragility functions empirically, analytical derivation of the fragility curves remains the best option.

The damage states and consequence functions are individually defined per content type. For instance, a desktop computer's overturning is paired with 100% probability of component replacement while the same damage state is assumed to result in replacement for only 30% of times for a bookcase [9]. In this study, a freestanding block has three damage states considered for sliding: (1) no damage, (2) limited sliding when *x* is less than 50 cm, and (3) excessive sliding when *x* is more than 50 cm. Similarly, two damage states are considered for rocking, namely, no damage and overturning when *θ*/*α* = 1. In case of anchored contents, four sliding damage states are considered: (1) no damage, (2) anchor breakage when the sliding displacement exceeds the yielding displacement of the cable, (3) limited sliding when $x$ is less than 50 cm, and (4) excessive sliding when $x$ is more than 50 cm. Finally, rocking is realized by three damage states of (1) no damage, (2) anchor breakage when the rotational angle exceeds the yielding rotation of the cable, and (3) overturning when $\theta/\alpha = 1$. These damage states are summarized in Table 1. Each damage state uses two $EDP_c$: $\theta/\alpha$, and $x$ as shown in Table 1.

The main objective of defining damage states is to derive the fragility functions by estimating the probability of sliding, rocking or overturning. From the dynamic response of rigid blocks at the different levels of Peak Horizontal Ground Acceleration (PHGA) for all ground motions, the failure probability is predicted as the number of cases that exceed the limit or damage states normalized to the total number of realizations. The data is represented by a lognormal fit using the method of least squares in order to find the fragility function parameters (median $\Theta$ and the dispersion $\beta$).

*Table 1. Performance criteria for the fragility functions of the content objects*

| **DS** | **$EDP_c$** | **Capacity limit states** | **Description** | **Seismic installation Condition** |
|---|---|---|---|---|
| DS0 | $\theta/\alpha,x$ | Initiation of rocking and sliding | No Damage | Free, Anchored |
| DS1 | $\theta/\alpha,x$ | Anchor breakage | Anchor Damage | Anchored |
| DS2 | $x$ | Limited sliding < 50 cm | Minor Damage | Free, Anchored |
| DS3 | $\theta/\alpha,x$ | Overturning, or excessive sliding > 50 cm | Major Damage to collapse | Free, Anchored |

In order to combine sliding and overturning a fault tree model is used to estimate the content loss for all damage states, the probability (P) of being in or exceeding a given damage state (DS) at a certain PHFA is given by:

$$\mathrm{P}\left[DS_j\middle|PHFA\right] = \max_{i=1,2}(\mathrm{P}_i[EDP_i \geq edp_i|PHFA]) \qquad (6)$$

While the $EDP_c$ for the $i^{th}$ failure mode (sliding or rocking) resulting in damage state $j$ and $edp_i$ are the capacity limit states. For example $\mathrm{P}_2[EDP_2 \geq edp_2|PHFA = 0.5g]$ for $DS_3$ denotes the probability that the object will overturn when $\theta/\alpha > 1$ at PHFA = 0.5 g. On the other hand, $P_1[EDP_1 \geq edp_1|PHFA = 0.5g]$ is the probability the object slides more than 50 cm at PHFA = 0.5 g.

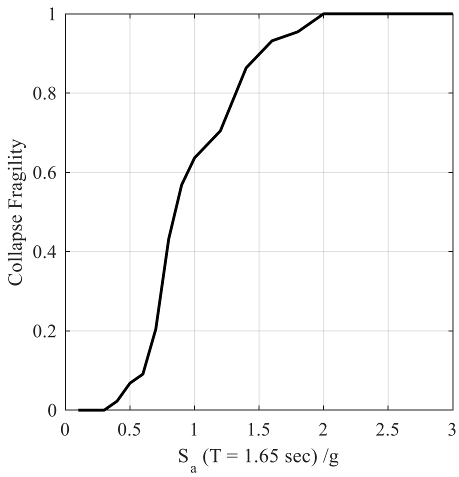
## CASE STUDY

This study considers two 4-story office buildings with steel and reinforced concrete moment frame systems located in a high seismic hazard zone. The structural characteristics of these reference models are summarized in Table 2. The nonlinear time history analyses are conducted on Clemson University's high-performance computer clusters (Palmetto). The building collapse fragility functions are derived by Incremental dynamics analysis (IDA) and peak floor accelerations at multiple spectral acceleration values are recorded during each simulation. Figure 2 presents the collapse fragility of steel and reinforced concrete moment frame.

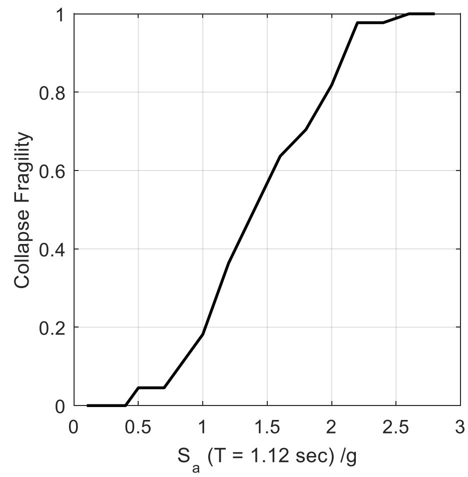
A total of 112 content objects (furniture and electrical appliances) are included in the generic office's assumed 70 $m^2$ consequence area. The components are grouped based on their characteristics (weight, aspect ratio, and friction coefficient), resulting in 21 distinct groups. The normative quantity of content, i.e., the quantity for each group of components per unit gross square area is estimated based on engineering judgment, the quantity value estimation was done based on Xactimate 2017 database [20], which is computer software that provides an estimate to personal property and emergency repairs. Overall, the total replacement cost of the office objects in 70 $m^2$ is estimated to be close to $70,000 (2018 USD). A sample of ten contents group sets out of 21 sets and their aspect ratios, friction coefficients, and quantity values are presented in Table 3.

*Table 2. The structural characteristics of the two reference models*

| **Reference Model** | **Model Dimension** | **Number of stories** | **Period (sec)** | **Analysis Platform** | **Source** |
|---|---|---|---|---|---|
| Steel moment frame | 2D | 4 | 1.56 | OpenSees [17] | [18] |
| Reinforced concrete moment frame | 2D | 4 | 1.12 | OpenSees [17] | [19] |




(1)




(2)

*Figure 2. Building Collapse Fragility: (1) steel moment frame (2) reinforced concrete moment frame.*

In order to derive sliding and rocking content fragility, an IDA performed on the four content models that have explained before. Figure 3 represents the probability of sliding failure in an anchored bookcase when subjected to limited and excessive sliding. As expected, the estimated failure probability of the anchored bookcase is less than the freestanding bookcase, for instance, at $S_a$ of 1.5g where the limited sliding probabilities are 60% and 40% for the freestanding and anchored cases, respectively. The rocking failure probabilities follow the same pattern.

*Table 3. A sample of office content objects*

| **No.** | **Component** | **Seismic Installation Condition** | **Aspect Ratio** | **Friction Coefficient** | **Set Value (USD)** |
|---|---|---|---|---|---|
| 1 | Large freestanding household equipment’s, e.g. small fridge | Free | 0.33 | 0.45 | 554 |
| 2 | Small countertop household electrical appliances, e.g. coffee machine | Free | 0.4 | 0.4 | 565 |
| 3 | House entertainment equipment e.g. audio systems | Free | - | 0.2 | 668 |
| 4 | Tableware, e.g. conference table | Free | 1 | 0.4 | 400 |
| 5 | Desktop Computer system unit | Free, Anchored | 0.5 | 0.4 | 2040 |
| 6 | Countertop contents with low base friction and low weight, e.g. glasses | Free | 0.25 | 0.2 | 350 |
| 7 | Bookcases, three shelves | Free, Anchored | 0.33 | 0.4 | 1480 |
| 8 | Vertical File Cabinets, four drawers | Free, Anchored | 0.3 | 0.4 | 750 |
| 9 | Furniture, e.g. seating | Free | 0.4 | 0.4 | 3885 |
| 10 | Multifunctional Printer | Free, Anchored | 0.5 | 0.45 | 867 |

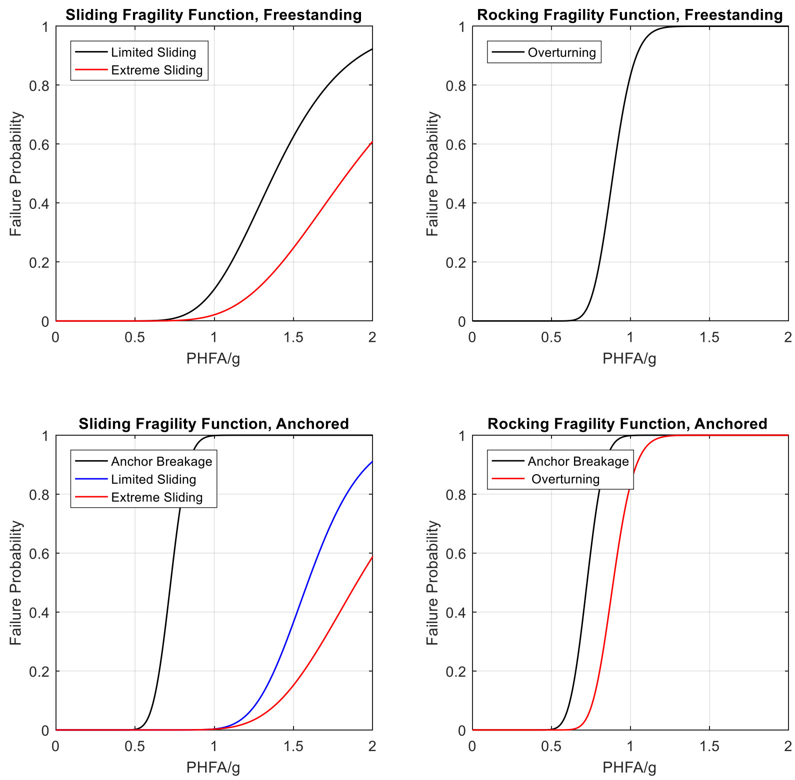



*Figure 3. Sliding and rocking fragility curves for the three-shelf bookcase in Table 3*

The content vulnerability functions refer to the normalized repair/replacement cost (i.e., the loss ratio) versus the spectral acceleration intensities at a given period of vibration with a 5% damping. A MATLAB toolbox is developed in this research to generate the vulnerability functions by three Monte Carlo simulation (MCS) modules. The flowchart of the methodology adopted from FEMA P-58 [2] shown in Figure 4. In each realization of MCS, 'collapse state' is checked first. If no collapse, a detailed loss estimation is conducted. The collapse state is checked using the collapse fragility curve obtained from IDA [21]. Accordingly, the content losses due to different failure modes, namely sliding and rocking, is estimated separately then the maximum loss of both is taken as the component loss according to Eq. 6.

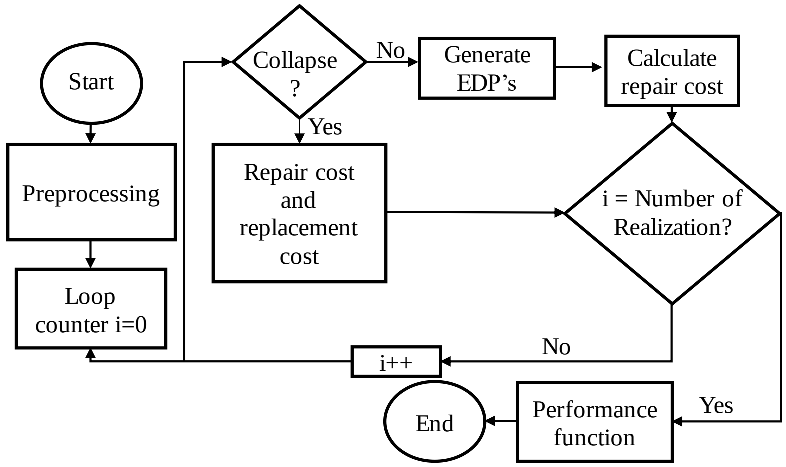
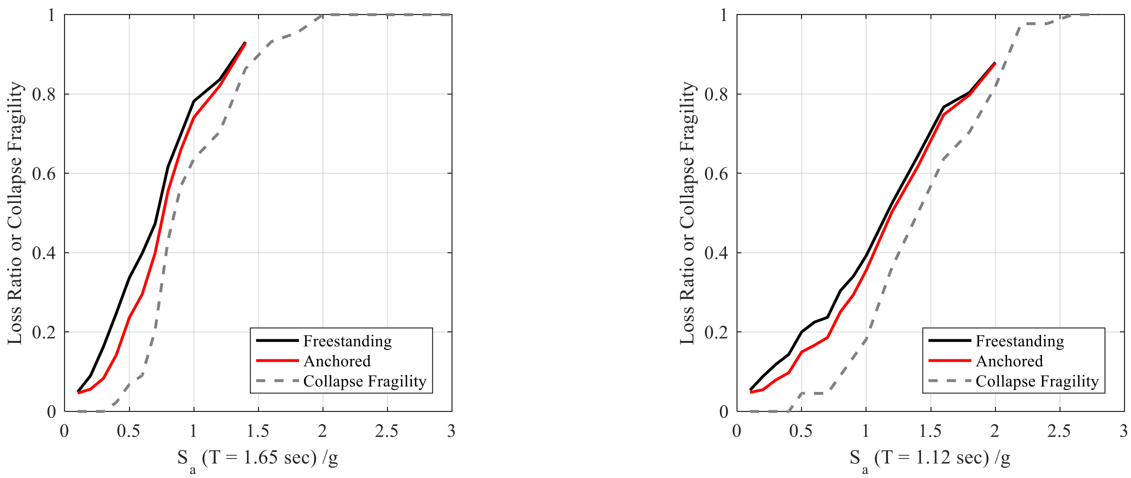



*Figure 4. The flowchart of the performance-based loss assessment procedure in the current version of FEMA P-58.*

According to Table 3, several object groups are freestanding while others may be anchored. Figure 5 compares the vulnerability functions for the case in which objects are freestanding versus the case where the anchorage option is taken for the applicable objects. Also depicted is the building's overall collapse fragility function. The reduction in loss ratio as the result of anchoring the applicable objects depends on the spectral acceleration level.




(1) (2)

*Figure 5. Content vulnerability function: (1) steel moment frame (2) reinforced concrete moment frame. Dashed lines indicate the building's overall collapse fragility curves.*

## CONCLUSIONS

Content damage has been shown to drive the earthquake losses for low to moderate intensity earthquakes over several occupancies but projecting content losses is challenging due to the lack of granular data from the past events. This study presented an analytical methodology to develop seismic content vulnerability functions for objects found in commercial environments. The methodology considers freestanding and anchored rigid block objects with damage states resulting from sliding, rocking and overturning. A set of fragility functions developed by performing incremental dynamic analysis in MATLAB in order to develop content vulnerability functions. A case study of two buildings were presented in which vulnerability functions were developed for four-story, steel and reinforced concrete, office building in the high seismic area. The following conclusions can be summarized from this study:

1. Contents are vulnerable to damage under low to moderate levels of earthquakes.
2. Free-standing contents are more vulnerable under earthquakes than the anchored contents, the probability of failure due to sliding, rocking and overturning reduces when the object is anchored
3. The building-level vulnerability (loss) function reduced for both the steel and reinforced concrete buildings when selective contents that can be anchored are anchored.
4. The reduction of the loss ratio between the freestanding and anchored contents depends on the hazard level. The reduction in the loss ratio between unanchored to anchored cases is most significant at low to moderate shaking intensity levels. However, at high shaking intensity level, the anchored and freestanding content losses are nearly identical.

## ACKNOWLEDGMENTS

This research was funded in part by AIG and the Risk Engineering and System Analytics center (RESA) at Clemson University. All results and findings are the opinion of the authors and do not reflect the views of AIG or RESA.

## REFERENCES

[1] ATC Performance of Buildings and Nonstructural Components in the 2014 South Napa Earthquake (FEMA P-1024). (2015)**.** 380.

[2] Applied Technology Council (ATC) FEMA P58-1: Seismic Performance Assessment of Buildings - Methodology. (2012). 1, 278.

[3] Rokneddin, K. , Safiey, A. , Javanbarg, M. , Manghnani, V. , and Pang, W. (2017). "Analytical content vulnerability assessment." *16th World Conference on Earthquake - WCEE*, Santiago, Chile.

[4] Abadi, H. A. Al , Lam, N. T. K. , and Gad, E. F. (2006). "Seismic fragility curves for damage to building contents." *Earthquake Engineering in Australia*, 161–168.

[7] Konstantinidis, D. and Markis, N. (2006). "Experimental and analytical studies on the seismic response of freestanding and reistained laboratory equipment." *Proceedings of the 8th U.S. National Conference of Earthquake Engineering*, Paper No. 1619.

[8] Lopez Garcia, D. and Soong, T. T. (2003). "Sliding fragility of block-type non-structural components. Part 1: Unrestrained components." *Earthquake Engineering and Structural Dynamics*, 32, 111–129.

[9] Jaimes, M. A. , Reinoso, E. , and Esteva, L. (2013). "Seismic vulnerability of building contents for a given occupancy due to multiple failure modes." *Journal of Earthquake Engineering*, 17, 658–672.

[10] Reinoso, E. , Jaimes, M. A. , and Esteva, L. (2010). "Seismic vulnerability of an inventory of overturning objects." *Journal of Earthquake Engineering*, 14, 1008–1021.

[11] Lopez Garcia, D. and Soong, T. T. (2003). "Sliding fragility of block-type non-structural components. Part 2: Restrained components." *Earthquake Engineering and Structural Dynamics*, 32, 111–129.

[12] Makris, N. and Zhang, J. (1999). "Rocking Response and Overturning of Anchored Equipment under Seismic Excitations." *Pacific Earthquake Engineering Research Center*, 1–82.

[13] FEMA P-695: Quantification of Building Seismic Performance Factors. (2009).

[14] Vamvatsikos, D. and Cornell, C. A. (2002). "Incremental dynamic analysis." *Earthquake Engineering & Structural Dynamics*, 31, 491–514.

[15] American Society of Civil Engineers ASCE. (2017). A. Minimum Design Loads and Associated Criteria for Buildings and Other Structures. Reston, Virginia, USA.

[16] MathWorks (2017). MATLAB R2017b. MathWorks, USA.

[17] Mazzoni, S., Mckenna, F., Scott, M.H., and Fenves, G.L.(2007). Open system for earthquake engineering simulation (OpenSees). UC Berkley, California, USA.

[18] National Institute of Standards and Technology (NIST) (2017). Seismic Analysis , Design , and Installation of Nonstructural Components and Systems – Background and Recommendations for Future Work.

[19] Haselton, C.B. Assessing seismic collapse safety of modern reinforced concrte moment frame buildings. (156) . (2007).

[20] Xactware (2018). Xactimate 28.

[21] Safiey, A. , Ziaei, E. , Gu, M. , Pang, W. , Rokneddin, K. , and Javanbarg, M. (2018). "Influence of irreparability fragility on seismic vulnerability assessment of buildings. " *Eleventh U.S. National Conference on Earthquake Engineering*, 19103.