Citation: Durán, S., T. Saito (2021), Basic study on the development of design code for seismically isolated buildings in El Salvador, Synopsis of IISEE-GRIPS Master's Thesis.

BASIC STUDY ON THE DEVELOPMENT OF DESIGN CODE FOR SEISMICALLY ISOLATED BUILDINGS IN EL SALVADOR.

Susan Durán[1,2] **Supervisor: Taiki SAITO[3]**

ABSTRACT

The current Urban Regulation in the Metropolitan Area of San Salvador (Master Plan, 2017) encourages the densification in the territory and promotes the growth in height due to the lack of land. The project developers are more interested in using new seismic response control systems. This study intends to propose a design procedure for seismically isolated buildings in El Salvador. A design of a base isolation system for the target building is conducted, applying the Capacity Spectrum Method and Time History Analysis (THA), following the Japanese Standard. The effect of the aspect ratio is analyzed by the history of axial forces of models with two aspect ratios, lower than and higher than 4, by THA and pushover. The capacity curves are associated with the tensile failure obtained by pushover, considering the "Ai" and uniform load distribution. The analysis of the history of axial forces of the two models proved the accuracy of the Japanese recommendation in terms of the aspect ratio in the isolated building. The significant effect of the type of horizontal load distribution was also analyzed on evaluating the tensile failure in the isolation devices using the capacity spectrum method. It is found that uniform load distribution is more appropriate in the capacity spectrum method.

Keywords: Design procedure, seismically isolated buildings, aspect ratio.

1. INTRODUCTION

El Salvador is located on the Pacific coast of Central America, in a region with high seismic activities within the Pacific Ring of Fire and is organized into 262 municipalities, 14 of them are part of the Metropolitan Area of San Salvador (AMSS), which is the most densely populated area in the country. According to the Salvadoran Chamber of Construction (CASALCO), between 2018 and 2021, the multi-story buildings built in the country will add 212 projects, representing 35% of the construction projects of the private sector. In 2018, the number of projects increased approximately three times the amount of the previous year. This trend highlights the urgency of updates to the regulations. The seismic isolation technique is new in El Salvador. The first project that includes this technique began construction in 2019. However, there are no regulations or technical methodology to analyze buildings with base isolation.

2. DESIGN ISOLATION LAYER OF THE TARGET BUILDING

2.1. Seismic isolation devices.

In the base isolation systems, the devices provide high lateral flexibility and damping properties to absorb the earthquake energy. The superstructure is separated from the ground movement, reducing the relative

[1] The Mayors Council and Planning Office of the Metropolitan Area of San Salvador, El Salvador.
[2] IISEE-GRIPS Master's course student.
[3] Professor, Department of Architecture and Civil Engineering, Toyohashi University of Technology.

lateral displacements of story, structural and non-structural damage, and protecting the content inside the buildings. This study is focused on the lead rubber bearing (LRB).

2.2. Description of the target building.

The main information of the target building is shown in Figure 1 and Table 1.

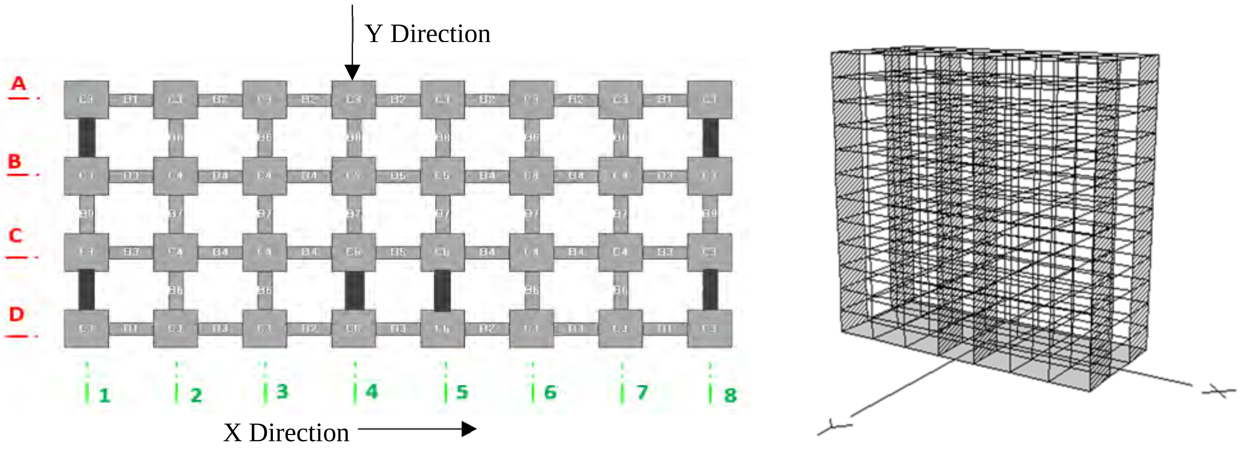

Figure 1. Typical floor plan and model of the target building. STERA 3D

Table 1. General information of the target building.

X DIRECTION	55.2	m
Y DIRECTION	18.8	m
HEIGHT	42.75	m
USE OF BUILDING	12-stories residential building	

2.3. Setting of the isolation devices.

The configuration of the isolation devices is shown in Figure 2. The isolated building achieved a natural period equal to 4.73 seconds. As shown in Table 2, the limit design deformation of LRB device is ${}_{m}\delta_{d}$ =47.7 cm.

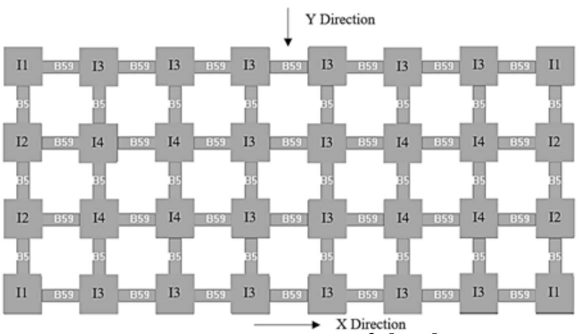

Figure 2. Arrangement of the devices.

Table 2. Characteristics of the isolation devices.

TYPE ISOLATION DEVICE	I1	I2	I3	I4
Diameter (cm)	70.00	80.00	85.00	90.00
S1: First shape factor	37.20	37.00	37.30	37.50
S2: Second shape factor	3.46	4.00	4.26	4.55
K1: Initial stiffness (KN/m)	9790.00	13000.00	14700.00	16600.00
K2: Secondary stiffness (KN/m)	753.00	1000.00	1130.00	1280.00
Q: Yield load (KN)	160.00	250.00	303.00	331.00
Limit design deformation ${}_{m}\delta_{d}$(cm)	**47.74**	55.87	59.91	63.36

2.4. Design procedure of the isolation layer by the Capacity Spectrum Method.

The response spectrum defined in the Salvadoran Technical Standard for Seismic Design (NTDS) with the conditions of the target building (Seismic zone 1, soil type S1, and the occupation category II), was used to carry out the design by capacity spectrum method, as shown in Figure 3. The deformations of the isolation layer are calculated by the capacity spectrum method for standard and lower limit conditions of device properties as shown in Figure 4. The requirement $\delta_{response} < {}_{m}\delta_{d}$ =47.7 cm is satisfied.

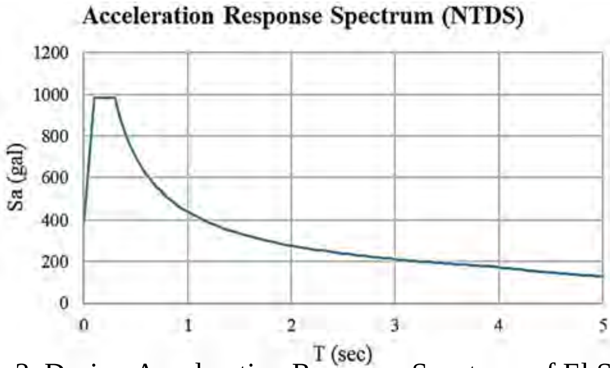

Figure 3. Design Acceleration Response Spectrum of El Salvador.

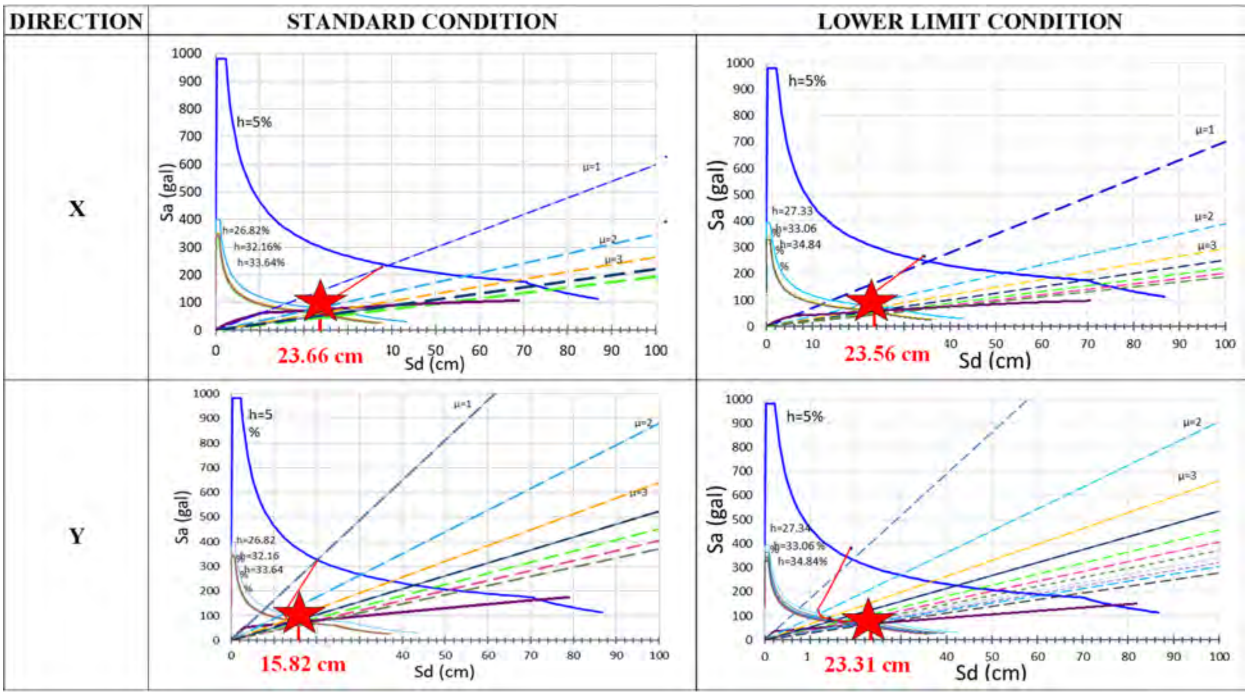

Figure 4. Results of Design by Capacity Spectrum Method.

2.5. Design procedure of the isolation layer by the THA.

Six input ground motions are used in the THA: two real data from El Salvador (the 1986 San Salvador and the 2001 El Salvador) and four artificial ground motions compatible with the design response spectrum of El Salvador (based on the 2001 El Salvador, the El Centro 1940, the Kobe 1995, and random phase). The summary of the results of the maximum displacement in the isolation layer is shown in Table 3. The requirement $\delta_{response} < {}_{m}\delta_{d}$ =47.7cm is satisfied.

Table 3. Results of THA (maximum displacement in isolation layer)

DIRECTION	TIME HISTORY ANALYSIS. LOWER LIMIT. MAXIMUM DISPLACEMENT IN ISOLATION LAYER (CM). LOWER LIMIT.					
	Original data of Earthquakes in El Salvador		Aritificial ground motions with response spectrum compatible with the design response spectrum of El Salvador			
	San Salvador 1986	El Salvador 2001	El Salvador 2001	El Centro, 1940	Kobe, 1995	Random Phase, 120 sec.
X	10.17	19.99	40.14	31.11	42.33	21.16
Y	21.36	14.66	45.95	43.89	39.69	27.84

2.6. Design procedure proposal based on the Japanese Methodology

The procedure for the design base isolation system proposed in this study based on the Japanese Standard is shown in Figure 5.

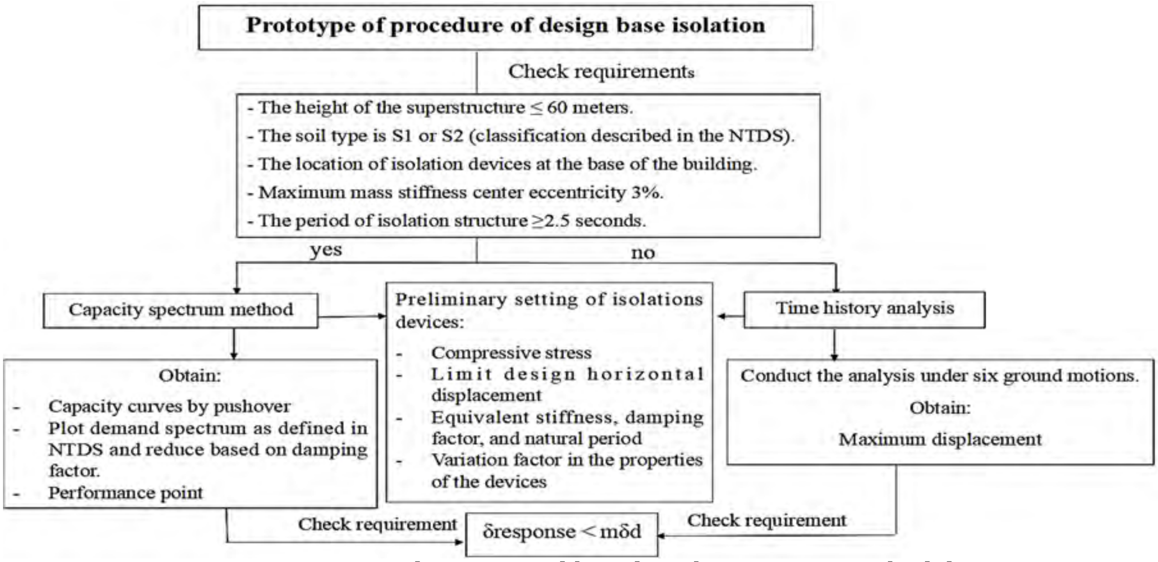

Figure 5. Design procedure proposal based on the Japanese Methodology.

3. ANALYSIS OF THE EFFECT OF THE ASPECT RATIO IN THE ISOLATED BUILDINGS.

A frame in the Y direction is chosen to develop the 2D model with an aspect ratio equal to 2.27. The accuracy of the model is checked by comparing the capacity curves of the 3D model with the 2D model, pushing in the Y and - Y directions. The curves of the 2D model are similar to the curves of the 3D model, as shown in Figure 6 for lower and upper limit conditions.

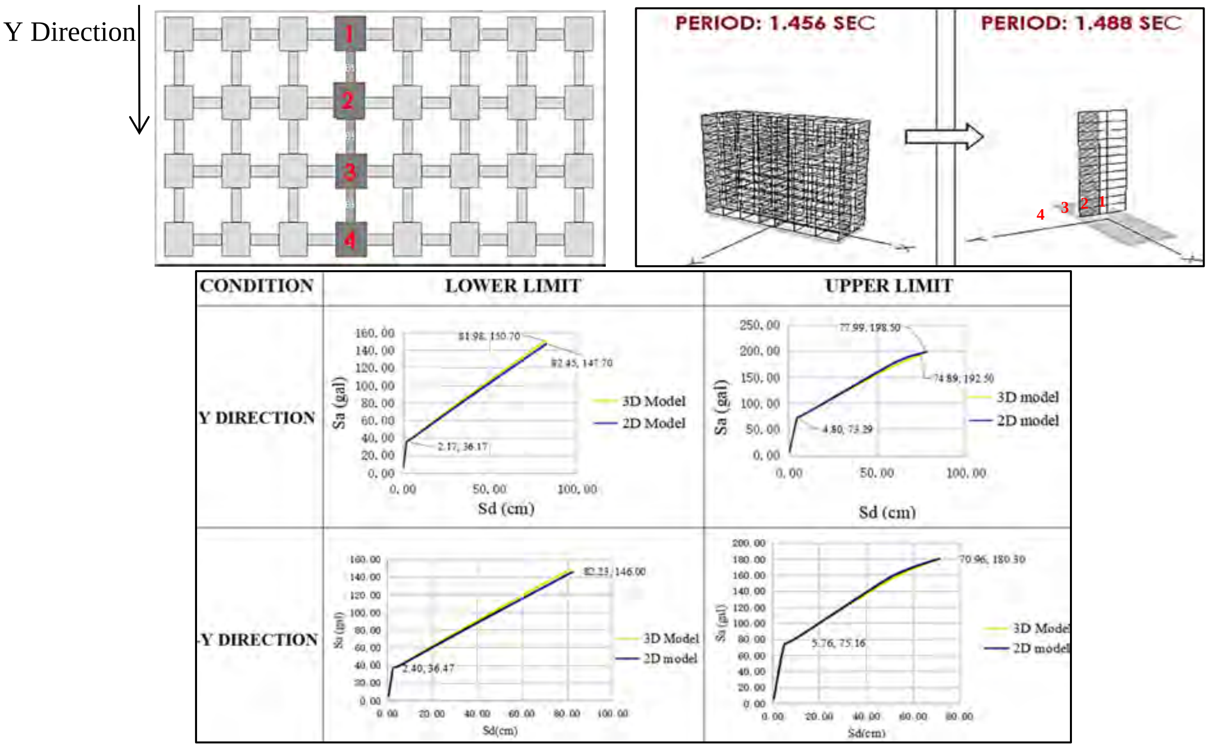

Figure 6. Device numbering and accuracy of the 2D model (aspect ratio equal to 2.27).

3.1. History of axial forces by the THA

Five input ground motions are used to analyze the history of axial forces by the THA: the 1986 San Salvador, the 2001 El Salvador, artificial ground motion based on the 2001 El Salvador, the El Centro 1940, and the Kobe 1995. The graphs of axial forces are obtained to check if the tensile stress is exceeded; this process is exemplified in Figure 7. After performing this analysis with the models with the aspect ratio equal to 2.27 and 4.5, the results showed that in the model with an aspect ratio of 2.27, the allowable tensile stress is not exceeded, but it is exceeded in the model with an aspect ratio 4.5.

The 1940 El Centro Earthquake Check tensile stress Device. No.4 LRBΦ850			
Allowable tensile stress : 1 MPa			
Lower Limit		**Upper Limit**	
Area (mm²):	567450.1731	Area (mm²):	567450.1731
Maximum Tension Force (N)	1259000.00	Maximum Tension Force (N)	4121000.00
Tensile stress (σ)	F/A	Tensile stress (σ)	F/A
Tensile Stress (MPa)	2.22	Tensile Stress	7.26
σ > Allowable Tensile Stress		σ > Allowable Tensile Stress	
Judge	**Exceed the limit**	**Judge**	**Exceed the limit**

Figure 7. Process of the analysis of history of axial forces by THA of the model with the aspect ratio equal to 4.5. Input ground motion: Artificial Earthquake based on the El Centro 1940.

3.2. History of axial forces by pushover

The history of axial forces is conducted considering the "Ai" and uniform load distributions. The graphs of axial forces are obtained, and the displacement where the tensile force reaches the allowable tensile stress is identified; this process is exemplified in Figure 8, and the results are presented in Table 4. The tensile failure occurs at smaller displacements when the load distribution "Ai" is considered.

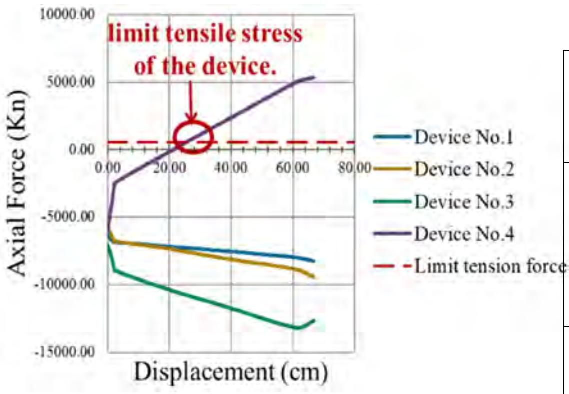

Figure 8. History of axial forces by THA of the model with the aspect ratio equal to 2.27.

Table 4. Results of ultimate point for tensile failure of the model with the aspect ratio equal to 2.27. considering "Ai" and uniform load distribution by pushover.

MODEL	CONDITION	DIRECTION	No. DEVICE	ULTIMATE POINT FOR TENSILE FAILURE (CM)	
				"Ai" load distribution	Uniform load distribution
ASPECT RATIO 2.27	Lower limit	Y	4	-	-
		-Y		39.20	62.50
	Standard	Y		-	-
		-Y		25.71	44.75
	Upper limit	Y		-	-
		-Y		12.85	29.00
ASPECT RATIO 4.50	Lower limit	Y	4	-	-
		-Y		31.80	51.50
	Standard	Y		-	-
		-Y		18.80	35.50
	Upper limit	Y		-	-
		-Y		7.70	21.25

3.3. Tensile failure of the device associated with the capacity curve.

The accuracy to consider the uniform load distribution in the capacity spectrum method to evaluate the tensile failure of devices is verified considering the acceleration displacement response spectrum of the input ground motions to get the performance points to compare them with the results obtained by the analysis of axial forces by the THA of the model with aspect ratio equal to 4.50. The results of the capacity spectrum method considering the uniform load distribution are compatible with the results of the THA, as shown in Figure 9.

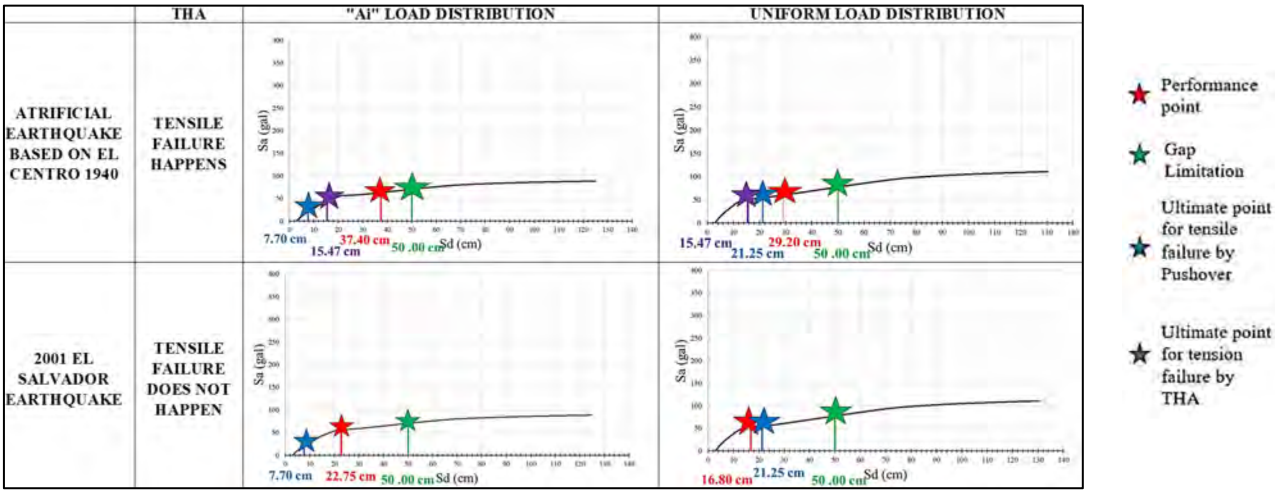

Figure 9. Results obtained by the THA and the capacity spectrum method of the model with aspect ratio 4.50

4. CONCLUSIONS

The isolation layer of the target building designed in this study based on the Japanese Standard using Capacity Spectrum Method includes three important design criteria: the ultimate shear strain of the device, the gap limitation, and the horizontal deformation at the tensile failure of the device.

The Japanese Standard considers "Ai" load distribution for the pushover analysis. However, in this study, it was found out that the deformation at the tensile failure of the isolation device largely depends on the load distribution, and the "Ai" distribution underestimates the deformation. This studied was focused on the load distribution of the capacity spectrum method. The accuracy of estimating the horizontal deformation at the tensile failure was discussed by models with two different aspect ratios (lower than and higher than 4) by comparing the THA. Through this study, it was found that uniform load distribution is more appropriate in the capacity spectrum method.

ACKNOWLEDGEMENTS

This research was conducted as the individual study of the training course "Seismology, Earthquake Engineering and Tsunami Disaster Mitigation" by IISEE/BRI, JICA, and GRIPS. To God first, the owner of my life. I want to express my sincere thanks to my supervisor Dr. Taiki Saito, advisor Dr. H. Suwada, the Course Leader Dr. T. Azuhata and all IISEE / BRI and JICA staff.

REFERENCES

American Society of Civil Engineers, 2016, Minimum Design Loads and Associated Criteria for Buildings and other Structures, United States of America.

Higashino, M., Okamoto, Sh., 2006, Response control and seismic isolation of buildings, International Council for Research and Innovation in Building and Construction, Japan.

Saito, T., Takano, S., 2017, Design Procedures of Response Spectrum Method and Time History Analysis of Seismic Isolation Buildings in Japan, Toyohashi University of Technology, Japan.

https://www.eleconomista.net/economia/El-Salvador-proyectos-verticales-suman-305-millones-20191031-0024.html