Seismic Evaluation of the Main Building at the Polytechnic University of Puerto Rico

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Abstract *— The Main Building at the Polytechnic University of Puerto Rico was originally built in 1933 to house the Hato Rey Psychiatric Hospital. It was acquired by the Institution in 1986 and since, it has been the Universities' most iconic landmark. As a national historic building, it must be preserved. One of the most critical analyses of historical buildings is their seismic adequacy. This report will perform a seismic analysis based on the Life Safety performance level. Site investigations and documents review showed that the building possesses a lateral force resisting system comprised of shear walls in both directions with rigid floor diaphragms. As a result, the building provides a Life Safety Basic Configuration performance level of 88%, a Life Safety Structural performance level of 75% and a Non-Structural performance level of 17%. This report should be the starting point for a decision making process that supports a more detailed analysis to improve these performance levels.*

Key Terms *— ASCE 41-13, Clínica Juliá, Existing Building, Life Safety Performance.*

INTRODUCTION

This report will evaluate the expected performance level of The Main Building at the Polytechnic University of Puerto Rico, in a seismic event. The building's structural system was evaluated for general conformance to the requirements of the American Society of Civil Engineers/Structural Engineering Institute standard ASCE/SEI 41-13 Seismic Evaluation and Retrofit of Existing Buildings [1], whose minimum seismic performance objective is Life Safety. It is assumed that structures that satisfy the Life Safety criteria of ASCE/SEI 41-13 [1] may be significantly damaged in an earthquake, but the occupants should be able to safely exit the building.

The ASCE/SEI 41-13 [1] is intended to replace FEMA 310, Handbook for Seismic Evaluation of Buildings—A Pre-standard (1998). This Standard was written to: reflect advancements in technology; incorporate the experience of design professionals; incorporate lessons learned during recent earthquakes; be compatible with FEMA 356, Pre-standard and Commentary for the Seismic Rehabilitation of Buildings (2000); be suitable for adoption in building codes and contracts; be nationally applicable; and provide evaluation techniques.

This standard is a nationally recognized standard, which goal is to identify the weak links in a building's lateral force resisting system that can lead to significant failure and/or collapse.

The evaluation is based on review of available construction drawings, non-destructive evaluation and on-site visual examination.

The design of measures to mitigate the deficiencies found is not addressed on this paper.

Seismic Evaluation Overview

Evaluating existing buildings for potential damage from earthquakes requires balancing structural engineering concerns with current state and federal policies as well as owner's conservation and risk policies in order to reduce seismic risks. Consequently, priorities must be developed regarding loss of life and/or building damage in a seismic event. Two main factors establish the priorities:

- The level of risk to life and property
- The level of risk to the structural elements of the building

Performance Based Evaluation

The purpose and methodology is to provide guidance in the review of a building's response to earthquake based on a "level of performance" philosophy.

ASCE/SEI 41-13 [1] recommends the use of a seismic force that varies depending on the expected level of performance of the structure. The desired level of performance is chosen by the owner in conjunction with the design professional and local building authorities. The level of performance may be either for Life Safety or Immediate Occupancy.

The Immediate Occupancy performance level allows very little damage to both structural and non-structural components during a design earthquake. The basic gravity and lateral-force-resisting system remains essentially intact. The level of risk for life-threatening injury as a result of damage is very low. Although some minor repairs may be necessary, the building is expected to be habitable and operational after the event. Repairs may be completed while the building is occupied.

Life Safety performance level allows for significant damage to both structural and non-structural components during a design earthquake. Some margin of safety against either partial or total collapse remains. Injuries may occur, but the level of risk for life threatening injuries and entrapment is low. In other words, substantial damage may be sustained by the building while still providing life safety protection for the occupants and the ability to egress safely - re-occupancy is a secondary concern.

For the purpose of this report the level of performance was chosen by the design professional without the involvement of neither the Owner nor local preservation and building authorities.

Regarding the methodology, the Tier 1 quick check employs a set of checklists for each building type. The checklist contains a set of evaluation statements (generally qualitative) which help identify areas of concern with regards to the structure's ability to adequately transmit earthquake forces to the foundation system and surrounding soils.

SCOPE OF WORK

The scope of work for the seismic evaluation for the Main Building of the Polytechnic University of Puerto Rico includes the following:

- Visual examination of the exterior and interior of the building
- Review of available construction documents
- Review and investigation of general information of the building (photos, newspapers, reports, etc.)
- Preparation of current structural as-built drawings showing the condition of the load resisting system.
- Provide a Tier 1 seismic evaluation for the structure using ASCE/SEI 41-13 [1]
- Develop preliminary recommendations to improve the level of performance of the building
- Provide a formal seismic evaluation report outlining and summarizing the findings and recommendations.

BUILDING DESCRIPTION

Ernesto Vazquez Torres (1907 – 1992) founded the Polytechnic University of Puerto Rico in 1966.

On December 23, 1986, Ernesto Vazquez Torres buys the premises from María Lina Juliá de Margarida [2], daughter of the original owner of the compound. The complex was known at that time as the Juliá Clinic, located on 377 Ponce de Leon Ave. A photo of the original structure is presented on Figure 1 [3].

On January of 1987 this building underwent a series of modifications commissioned by the Polytechnic University of Puerto Rico in order to fulfill its needs as an educational institution. Before that, from 1933 till 1985 the building also increases its square footage, as originally it had 14,325 sft.

Figure 1
Hato Rey Psychiatric Hospital in the 30's

The 1987 remodeling was design by the firm of J. L. Cajigas & Associates [4]. As part of the drawings, an as-built of the clinic was prepared, as well as all proposed modifications.

By the summer of 1988 the project was completed and began its use as the Polytechnic University of Puerto Rico.

On 1989, the firm of Antonio Suarez Garcia Architects [5] presented the design of the new library facility. It was located on the north open patio of the building. The structural system used was a two story steel frame system with steel joists and RC slab over a metal deck. That same year, drawings were also prepared by Antonio Suarez Garcia Architects to provide a new elevator and steel stair [6].

Since then, minor modifications have been made to meet the growing demands and additional services provided by the institution.

Today, The Main Building is approximately 56,700 square foot structure that houses the administration offices in the first floor, presidential, administrative and professor offices in the second floor and classrooms in the third floor. It also has a basement space.

Structural System

A series of reinforced concrete walls, in both directions, were identified as part of the lateral-force-resisting system.

The thickness of these walls was measured to be 8 inches and the opening for the corridors, windows and doors was considered when analyzing the shear strength of these walls.

In the north-south direction seven shear walls were identified marked as red in Figure 2 and in the east-west direction, six shear walls were identified marked as blue in Figure 2.

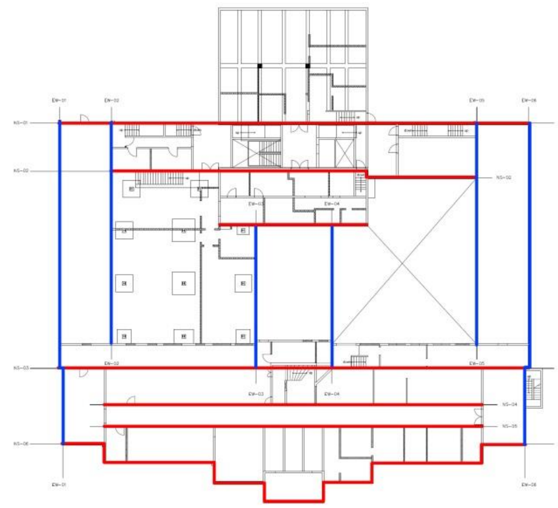

Figure 2
Lateral Force Resisting System, First Floor As-Built 2015

The floor diaphragms were considered to be rigid, thus transferring lateral loads to the shear walls.

Non-Destructive Investigation

As part of the investigation, and in order to validate the seismic-force-resisting system, non-destructive testing was performed. This allowed the investigation to discern between structural and non-structural elements. In the case of structural elements, it provided valid information in determining the spacing of vertical and horizontal reinforcing steel as well as their diameter.

The instrument adopted to determine the reinforcement of structural walls was the Profometer 5 Rebar Locator manufactured by PROCEQ Testing Instrument available at the Structural Engineering Laboratory of the Polytechnic University of Puerto Rico. Figure 3 shows an example of rebar diameter and concrete cover determination. In this case a portion of the rebar is exposed, thus validating the accuracy of the test.

The Profometer 5 metal locators use the Pulse Induction Eddy Current technique to locate the reinforcing steel. It is based on electromagnetic pulse induction technology. Coils in the probe are periodically charged by current pulses and thus generate a magnetic field. Reinforcing bars that are closer to the probe or of larger diameter produce a stronger magnetic field, thus identifying the rebar location and diameter.

This equipment limits the detection of the diameter of the reinforcing steel to a maximum cover of 2.25 inches with an accuracy of ± 1/16 in. Thicker concrete cover impairs the capabilities of the probe to estimate the steel diameter.

The non-destructive evaluation performed on the Main Building provided a clear understanding of the lateral-force-resisting system. A group of reinforced concrete walls were selected in order to assign the lateral loads to be applied as part of the quick checks, in addition to determine the vertical and horizontal reinforcement.

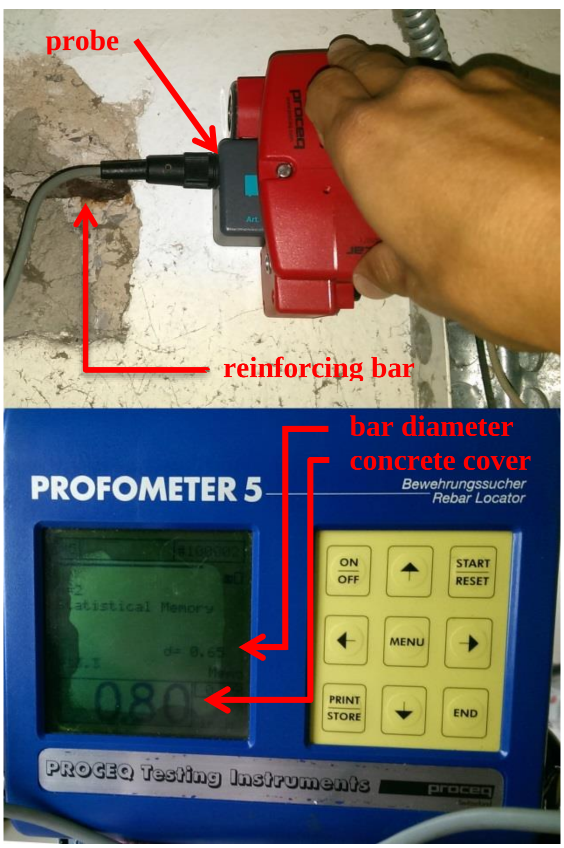

Figure 3
Non-Destructive Evaluation

The analyses performed as part of this report adopts a reinforcement of #4 @ 12" e.w. as determined by the non-destructive testing.

SEISMIC EVALUATION

During a seismic event, the horizontal acceleration of the ground induces inertial forces in buildings. These forces are proportional to the building weights; they are primarily horizontal (lateral) and must be resisted by the buildings lateral force-resisting-system. If the structures cannot resist the lateral forces induced by the seismic ground motion, they would suffer damage to both structural and non-structural elements and potentially collapse.

All buildings have some minor level of inherent lateral force resistance, simply due to the nature of how various building materials are connected and constructed. The seismic evaluation of a building simply determines the level to which the individual elements can resist the recommended earthquake forces.

The lateral force-resisting-system of The Main Building at the Polytechnic University of Puerto Rico was described previously. Inertial forces generated in the building must be transfer to the foundation through a continuous load path. Forces in the system are transferred to the walls via diaphragm action of the roof or floors.

Analysis

As discussed earlier, the analysis for the Tier 1 consists of checklists composed primarily of qualitative evaluation statements. The purpose of the checklists is to identify deficiencies. Further analysis of these potential deficiencies may show that they are acceptable. For the original building, and the additions, the checklist for building type C-2 (Shear Walls with Rigid Diaphragms) was used to correspond with the primary lateral force-resisting system of the structure, in addition to the non-structural components checklist.

PERFORMANCE OBJECTIVE AND SEISMIC HAZARD

The building performance can be described qualitatively in terms of the safety afforded to building occupants during and after the event; the cost and feasibility of restoring the building to its pre-earthquake conditions; the length of time the building is removed from service to effect repairs; and economic, architectural or historic effects on the larger community.

This paper considers the following parameters following the ASCE/SEI 41-13 [1] controls for the Life Safety Evaluation, to perform the Tier 1 evaluation:

Table 1
Basic Performance Objectives for the Main Building

BASIC PERFORMANCE OBJECTIVES		
ASCE/SEI 41-13 REFERENCE	CATEGORY	PARAMETER SELECTED
Table 2.1	Risk Category	Life Safety Structural Performance / Position Retention Nonstructural Performance
Table C2.3	Damage Control and Building Performance Level	Life Safety Level (3-C)
§ 2.3.1	Structural Performance Level	Life Safety (S-3)
Table C2.5	Nonstructural Performance level and Illustrative Damage	Life Safety (N-C)
Table C2-8	Target Building Performance Level	Life Safety (3-C)

Based on the parameters selected on table 1, the Target Building Performance Level results in an expected post-earthquake damage state of Life Safety (S-3). This state expects the structure to remain stable and with significant reserve capacity; hazardous nonstructural damage controlled.

Seismic Hazard

The seismic hazard caused by ground shaking was based on the location of the building with respect to the regional and site-specific geologic and geotechnical characteristics and the specific Seismic Hazard Level.

The Basic Safety Earthquake-1 for use with Basic Performance Objective for Existing Buildings (BSE-1E) taken as a seismic hazard with a 20% probability of exceedance in 50 years was used to determine the Spectral Response Acceleration Parameters. These are the design short-period spectral response acceleration parameter, S_{xs}, and the design spectral response acceleration parameter at a 1-s period, S_{x1}.

The soil were the building is located is classified as Site Class D corresponding to a stiff soil with a blow count (N) of 15<N≤50.

Based on the Puerto Rico Building Code 2011 [7], Table 1613.5 (13) – *Spectral Response Accelerations for Municipalities of Puerto Rico, % of g for the Municipality of San Juan*, the short-period spectral response acceleration and the spectral response acceleration at 1-s period are $S_{XS} = 0.90g$, $S_{X1} = 0.310g$ respectively.

The level of seismicity is determined using the design spectral response acceleration parameters calculated by (1) and (2).

$$S_{DS} = \frac{2}{3} S_{XS} = 0.60 \quad (1)$$

$$S_{D1} = \frac{2}{3} S_{X1} = 0.21 \quad (2)$$

From ASCE/SEI 41-13 [1] table 2-5 and using the values calculated above, S_{DS} provides a moderate level of seismicity and value S_{D1} provides a high level of seismicity, thus the level of seismicity for the site is high.

TIER 1 ANALYSIS

A series of site visits were performed to explore the conditions of building configuration, components, site and adjacent structures among other observations. Existing building characteristics pertinent to seismic performance were obtained from the following sources:

- Field observations of existing conditions and configurations.

- Construction documents located on the University's library and General Services Office.
- Non-destructive examination.
- Interview with University personnel.

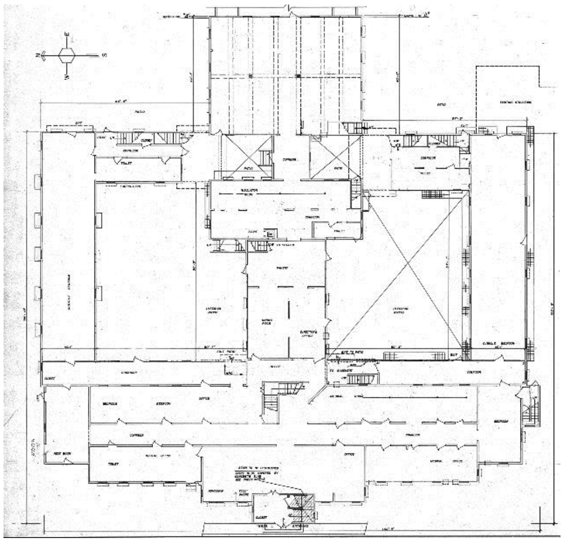

Figure 3
First Floor As-Built of 1986

Building Type

Based on the sources described above, the building is classified as type C2 – Concrete Shear Walls with Stiff Diaphragms. This building consists of floor and roof framing of cast-in-place concrete slabs, concrete beams and flat slabs. Floors are supported on bearing walls. Seismic forces are resisted by cast-in-place concrete walls on both cardinal directions.

Quick Checks

The following calculations have the intention of determining the stiffness and strength of building components. They are required to define whether the building complies with certain evaluation criteria.

Fundamental Period of Vibration of the Building

From ASCE/SEI 41-13 [1], section 4.5.2.4, the numerical value *Ct*, for adjustment of the fundamental period of the building, for all other lateral force resisting systems other than: moment resisting frames of steel and concrete and eccentrically braced steel frames is *0.020*. The adjustment factor β, for the empirical fundamental period of the building, for all other lateral force resisting systems other than: moment resisting frames of steel and concrete and eccentrically braced steel frames is *0.75*.

The height of the building is *37.5ft*, thus the fundamental period of vibration of the building results to be:

$$T = C_t h_n^{\beta} = 0.303 \text{ s} \quad (3)$$

Spectral Acceleration

Using the values determined in (2) of this paper, the spectral response acceleration is:

$$S_a = \frac{S_{x1}}{T} = 1.02 \quad (4)$$

As per ASCE/SEI 41-13 [1], section 4.5.2.3, the spectral response acceleration can't exceed the design spectral response acceleration parameter at a 1-s period, *Sxs*, which was found to be *0.90g*. Thus *Sa = 0.90g*.

Effective Seismic Weight of the Building

In order to determine the effective seismic weight of the building the following parameters were considered:

- Weight of reinforced concrete members like: slabs, beams, toppings supported by steel beams and toppings supported by metal deck
- Reinforced concrete columns
- Reinforced 8 inches concrete walls
- Unreinforced 6 inches block walls
- Steel beams
- Steel columns
- A partition load allowance of *10 psi* was applied to all floor area (ASCE/SEI 41-13 [1] section 4.5.2.1.2)
- The total operating weight of permanent equipment (ASCE/SEI 41-13 [1] section 4.5.2.1.3)

The results of the effective seismic weight of the building are presented on table 2 and 3 below. The weight of each floor is calculated individually and presented on table 2 and the cumulative effective seismic weight of the building is presented on table 3.

Table 2
Calculation of the Effective Seismic Weight of the Building

STORY	FLOOR AREA (ft2)	STORY HEIGHT (ft)	HEIGTH h (ft)	WEIGHT PER FLOOR w (kips)
3	17,185	12.7	37.5	4,591
2	19,531	12.7	24.8	4,778
1	19,983	12.2	12.2	4,458
	56,699		37.5	

Table 3
Cumulative Seismic Weight of the Building

STORY	CUMMULATIVE WEIGHT (kips)
3	4,591
2	9,369
1	13,827

Pseudo Seismic Force

From ASCE/SEI 41-13 [1] section 4.5.2.4 and the number of stories of the building, which for this project is three, the Modification Factor to relate expected maximum inelastic displacement to displacements calculated for linear elastic response, *C* for a building type C2 – Concrete Shear Walls with Stiff Diaphragms is *1.1*.

The Pseudo Seismic Force is calculated as follows:

$$V = CS_aW = 13{,}689\ kips \tag{5}$$

Story Shear Forces

The Pseudo Seismic Force calculated above is distributed vertically in accordance with (5) and (6). For buildings six stories or fewer height, the value of *k* shall be permitted to be taken as *1.0*.

$$F_x = \frac{w_x\, h_x^k}{\sum_{i=1}^{n} w_x\, h_x^k} V \tag{6}$$

Where the distribution of the Story Shear is presented in table 4, below:

Table 4
Story Shear Force

STORY	$w_x h_x^k$ (kips-ft)	$\frac{w_x h_x^k}{\sum_{i=1}^{n} w_x h_x^k}$	F_x (kips)
3	172,209	50%	6,830
2	118,678	34%	4,707
1	54,258	16%	2,152
	345,144		13,689

Shear Stress in Shear Walls

Equation (7) illustrates the average shear stress in the shear walls v_j^{avg}. This value represents the component of stress coplanar with the walls cross section per floor in each direction.

$$v_j^{avg} = \frac{V_j}{M_S\ A_W} \tag{7}$$

Where: v_j is the story shear at level j, A_w is the summation of the horizontal cross-sectional area of all shear walls in the direction of loading and M_s is the system modification factor for shear walls depending on the Level of Performance and the Type of wall. For a Level of performance of Life Safety and a reinforced concrete shear wall, the value of $M_s = 4$. The values of v_j are presented on table 5 and 6.

Table 5
Average Story Shear per Floor N-S Direction

	North-South Direction			
Floor	V_j (lbs)	A_w (in2)	v_j (psi)	< *100* (psi)
3	6,829,963	49,856	34.2	OK
2	11,536,822	61,624	46.8	OK
1	13,688,724	62,408	54.8	OK
			135.9	

Table 6
Average Story Shear per Floor E-W Direction

	East-West Direction			
Floor	Vj (lbs)	A_w (in2)	v_j (psi)	< 100 (psi)
3	6,829963	39,174	43.6	OK
2	11,536,822	40,550	71.1	OK
1	13,688,724	42,126	81.2	OK
			122.6	

Shear Stress Check

As per ASCE/SEI 41-13 [1], section A3.2.2.1, the maximum allowed SHEAR STRESS in concrete shear walls is *100 psi*. According to the results presented on table 5 and 6, the overall strength of the building is over the overall level of demand on the structure.

Tier 1 Results Evaluation

Table 7 summarizes the results based on the Tier 1 evaluation criteria.

Table 7
Summary of Tier 1 Evaluation Results

AREA	C	NC	N/A	U	TOTAL	%C
LIFE SAFETY BASIC CONFIGURATION CHECKLIST ITEMS						
General	2	0	1	0	2	100%
Building Configuration	6	0	0	0	6	100%
Geological Site Hazard	3	0	0	0	3	100%
Foundation Configuration	1	0	0	1	2	50%
LIFE SAFETY STRUCTURAL CHECKLIST ITEMS						
Seismic-Force-Resisting System	3	0	2	2	5	75%
Connections	1	0	1	2	3	50%
Diaphragms	2	0	0	0	2	100%
NON-STRUCTURAL CHECKLIST ITEMS						
Life Safety System	1	0	0	0	1	100%
Ceiling	0	2	0	0	2	0%
Light Fixtures	0	1	0	0	1	0%
Stairs	0	0	0	1	1	0%
Mechanical and Electrical Equipment	0	3	0	0	3	0%
Elevator	0	0	0	2	2	0%

C=compliant; NC=non-compliant; N/A=not applicable; U=unknown; %C=percent compliance

The results of the Tier 1 evaluation are analyzed as follow:

- If the item is not applicable, then it is not counted.
- Items NC and U are counted as non-compliant. Once the unknown items are verified, they can be categorized and the percent compliance revised.

Conclusion

This study leads to the following conclusions:

- The basic configuration of the building provides a level of compliance of 88%. Twelve out of the thirteen items were in compliance. The compliance of the continuity of the rebar from the shear walls to the foundation couldn't be verified, thus this item is unknown. Further investigation is required to determine if it complies. In case that item is found to be in compliance, the level of compliance will raise to 100%.
- The seismic-force-resisting system of the Main Building provides a Life Safety Structural Performance Level of 75%. Six out of the eight items were in compliance. The connections between diaphragms and walls couldn't be verified, thus these items are unknown. Further investigation is required to determine if they comply. In case that these items are found to be in compliance, the level of compliance will raise to 100%.

- For non-structural elements, the Life Safety Nonstructural Performance Level is 17%. Out of the ten items evaluated, one is in compliance, three are unknown and six are non-compliant. Further investigation is required to determine if they comply. In case that these three unknown are found to be in compliance, the level of compliance will raise to 25%. The non-structural items in the building need to be brought to code in order to avoid injuries to the users in case of a seismic event.

From visual inspection, exploratory investigations and the results of the Tier 1 evaluation, we present the following recommendations:

Destructive testing and advance exploration methods must be performed to determine the adequacy of the following:

- Presence of foundation ties to resist seismic forces.
- Spacing of stirrups in coupling beams over means of egress.
- Confirmation of reinforcing steel location and steel area provided.
- Continuity of vertical wall reinforcement into foundation.

Non-structural elements of the building are required to be properly anchored and/or braced to the structure in order to improve the level of safety for the users.

A Tier 2 evaluation should be conducted to provide a detailed understanding of the structural performance of the building.

The preservation of this landmark of the institution should be the driving force behind the interest of continuing research to improve de adequacy and the performance level of the building.

Academic resources of the institution should be used and targeted to contribute research to improve the level of compliance of the building.

Preservation shall be as important as the desire to develop new facilities for the university community.

References

[1] American Society of Civil Engineers / Structural Engineering Institute, “Seismic Evaluation and Retrofit of Existing Structures,” ASCE/SEI 41-13, 2013, pp. 518.

[2] El Politécnico, “Historia de la Clínica Dr. Mario Juliá García,” 1986.

[3] Historic Archives of the Polytechnic University of Puerto Rico Library, various, *Photos.*

[4] J. L. Cagigas & Associates, *Remodeling and Reconstruction Plans for the Polytechnic University of Puerto Rico,* 1986.

[5] A. Suárez García Architects, *Library Plans for the Polytechnic University of Puerto Rico,* 1989.

[6] A. Suárez García Architects, *Elevator and Metal Stair Addition for the Polytechnic University of Puerto Rico*, 1989.

[7] Oficina General de Permisos, *Puerto Rico Building Code*, 2011, pp. 178.