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Comparison of the FEMA P-154 Methodology with Seismic Analysis in the "Galería Tradición" of Cercado de Lima

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Abstract **-** The seismic vulnerability of buildings with considerable age represents a crucial challenge for urban resilience in a historic city like Lima. In this research, a sample of 30 publicly accessible galleries within the Cercado de Lima was evaluated. These structures were built with now-obsolete structural systems and are subject to deteriorated conditions. The FEMA P-154 methodology was applied to conduct rapid visual inspections and to classify the structures according to their level of seismic vulnerability based on the score established by the format. Additionally, a gallery with a critical FEMA score was selected for structural modeling in ETABS using previously scaled historical seismic records, following the guidelines of the E.030 Seismic Design Code. A Schmidt hammer test was also conducted to estimate the concrete strength of the selected building. The results show that more than one-third of the buildings exhibit high vulnerability and that the drifts obtained in the dynamic analysis exceed the limits established by the E.030 code. The FEMA P-154 methodology proved to be an effective tool for prioritizing structural interventions in urban contexts with limited resources.

Keywords**:** Seismic vulnerability, FEMA P-154, old galleries, rapid visual inspection, ETABS.

1. Introduction

Peru is one of the countries with the highest seismic activity in the world due to its location along the Pacific Ring of Fire, a region characterized by the interaction between the Nazca Plate and the South American Plate. This tectonic setting has placed Peru and its capital, Lima, in multiple high-magnitude seismic scenarios throughout history. Historically, the city of Lima has experienced several seismic events that have caused significant economic, structural, and social damage, including those that occurred in 1746, 1940, 1966, and 1970.

In the urban context of Lima, the district of Cercado de Lima represents a critical area for two main reasons. First, the district contains a high percentage of old buildings constructed before the implementation of modern seismic-resistant design standards. Second, many of these structures were originally residential dwellings that have been converted into publicly accessible commercial galleries, which accommodate a high density of people during long hours of the workweek. Added to this is the number of informal structural modifications carried out without prior studies, professional supervision, or adequate maintenance over time. This combination of factors significantly increases the risk in the event of a moderate-magnitude earthquake.

Evaluating the seismic vulnerability of buildings in this area is a priority for urban risk management. However, conducting a detailed inspection of each structure requires considerable investment in time, human resources, and funding. For this reason, there is a pressing need to implement rapid and effective methods that allow for preliminary mapping of which structures exhibit higher vulnerability and require urgent intervention. In this context, the FEMA P-154 methodology presents itself as a useful and internationally validated tool for conducting rapid visual inspections and classifying structures according to their level of seismic vulnerability.

The main objective of this research is to assess the seismic vulnerability of 30 old commercial galleries located within Cercado de Lima through the application of the FEMA P-154 method. Furthermore, the study aims to validate the method's effectiveness with the support of structural modeling in ETABS of a representative case, using accelerograms from historical earthquakes.

This comprehensive approach combines both qualitative and quantitative methods, offering a more complete overview of the seismic risk faced by these buildings. The results obtained from the research aim to provide technical evidence to support the implementation of rapid visual inspection methodologies for future mitigation actions by local authorities, heritage institutions, and risk management agencies.

2. Methodology

This research adopts an approach aimed at a preliminary evaluation of the seismic vulnerability of old commercial buildings in the district of Cercado de Lima. To achieve this, rapid visual inspection techniques, structural modeling using software, and a Schmidt hammer test were integrated to obtain a reliable characterization of the structural condition of these constructions.

a. FEMA P-154 Methodology: This is a standardized procedure for identifying potentially vulnerable buildings through rapid visual inspections (Federal Emergency Management Agency, 2015). The evaluation is carried out using data collection forms adapted to the type of structure and the seismic risk present in the area.
b. Schmidt Hammer Test: A non-destructive test used to estimate the compressive strength of concrete through the correlation between the applied stress and the rebound number indicated by the Schmidt hammer. It is employed to calculate the average concrete strength in the building selected as the case study.

3. Procedure

The procedure was divided into four stages: sample selection, application of the FEMA P-154 methodology, execution of Schmidt hammer tests, and computational modeling with dynamic analysis. These phases complement each other, allowing the validation of qualitative information obtained through visual observations using numerical simulation tools and indirect measurement of material properties.

3.1. Sample selection

A total of 30 buildings functioning as publicly accessible commercial galleries, located within the urban area of Cercado de Lima, were selected. The selection criteria included: age over 40 years, commercial use, a structural system consisting of reinforced concrete frames or mixed systems, and visual accessibility for both interior and exterior evaluation. Preliminary information was gathered through municipal cadastral records, satellite imagery, and documented site visits.

Among the galleries analyzed, Galería Tradición one of the most critical cases was selected for the subsequent comparison between the visual inspection methodology and dynamic analysis.

3.2. Application of the FEMA P-154 methodology

According to the guidelines of the Federal Emergency Management Agency (2015), the third edition of FEMA P-154 comprises a combination of qualitative tools for the rapid visual screening of buildings, based on a structured and standardized process that enables the identification of constructions potentially vulnerable to seismic events. The procedure begins with the collection of general information about the building such as its location, usage type, and number of stories followed by the identification of its structural typology from a predefined catalog provided in the format.

Subsequently, an exterior visual inspection is carried out, and an interior inspection as well if accessible. During this process, several aspects are evaluated: the presence of plan or vertical irregularities, the structural conservation condition, the presence of critical elements, and any possible structural deficiencies. These factors are used to assign a score (RVS score) that reflects the building’s level of seismic vulnerability. If the score falls below a determined threshold, the building is considered a priority for a more detailed evaluation due to its high vulnerability.

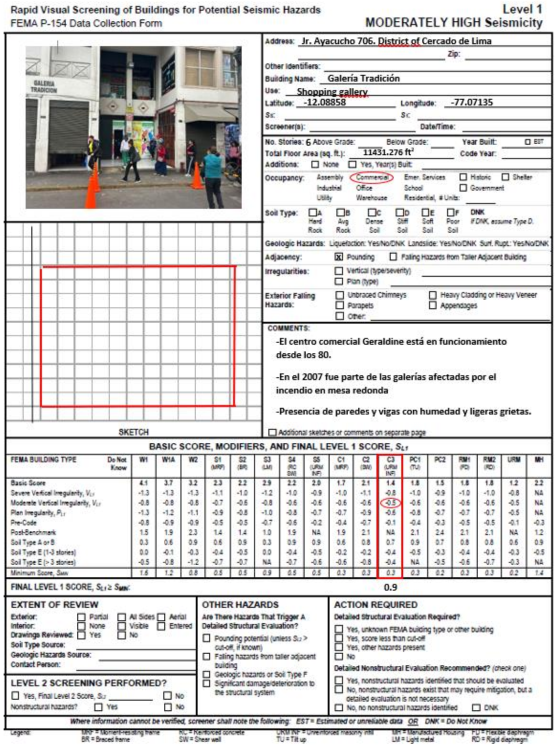
In the FEMA P-154 guide, a base score is calculated based on the structural typology of the inspected building and is then adjusted by subtracting penalties associated with the presence of unfavorable characteristics.

$$S = B - \sum_{i=1}^{n} P_i \tag{1}$$

Where:

- S = Final score
- B = Base score according to structural typology
- P_i = Penalty for each unfavorable condition observed (e.g., plan irregularities, vertical irregularities, soil type, age, etc.)
- n= Total number of applicable penalties

After conducting the exterior and interior visual inspection of the previously selected gallery, a score of 0.9 was obtained. According to the FEMA P-154 guidelines, this indicates that the structure exhibits good seismic resistance.



Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form

Level 1
MODERATELY HIGH Seismicity

Address: Jr. Ayacucho 706. District of Cercado de Lima
Zip:
Other Identifiers:
Building Name: Galería Tradición
Use: Shopping gallery
Latitude: -12.08858 Longitude: -77.07135
S_S: S_1:
Screener(s): Date/Time:

No. Stories: 6 Above Grade: Below Grade: Year Built: ☐ EST
Total Floor Area (sq. ft.): 11431.276 ft^2 Code Year:
Additions: ☐ None ☐ Yes, Year(s) Built:
Occupancy: Assembly [✓ Commercial] Emer. Services ☐ Historic ☐ Shelter
Industrial Office School ☐ Government
Utility Warehouse Residential, # Units:
Soil Type: ☐ A Hard Rock ☐ B Avg Rock ☐ C Dense Soil ☐ D Stiff Soil ☐ E Soft Soil ☐ F Poor Soil DNK If DNK, assume Type D.
Geologic Hazards: Liquefaction: Yes/No/DNK Landslide: Yes/No/DNK Surf. Rupt.: Yes/No/DNK
Adjacency: ☒ Pounding ☐ Falling Hazards from Taller Adjacent Building
Irregularities: ☐ Vertical (type/severity) ☐ Plan (type)
Exterior Falling Hazards: ☐ Unbraced Chimneys ☐ Heavy Cladding or Heavy Veneer ☐ Parapets ☐ Appendages ☐ Other:

COMMENTS:

-El centro comercial Geraldine está en funcionamiento desde los 80.

-En el 2007 fue parte de las galerías afectadas por el incendio en mesa redonda

-Presencia de paredes y vigas con humedad y ligeras grietas.

☐ Additional sketches or comments on separate page

SKETCH

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

FEMA BUILDING TYPE	Do Not Know	W1	W1A	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM	MH
Basic Score		4.1	3.7	3.2	2.3	2.2	2.9	2.2	2.0	1.7	2.1	1.4	1.8	1.5	1.8	1.8	1.2	2.2
Severe Vertical Irregularity, V_{L1}		-1.3	-1.3	-1.3	-1.1	-1.0	-1.2	-1.0	-0.9	-1.0	-1.1	-0.8	-1.0	-0.9	-1.0	-1.0	-0.8	NA
Moderate Vertical Irregularity, V_{L1}		-0.8	-0.8	-0.8	-0.7	-0.6	-0.8	-0.6	-0.6	-0.6	-0.6	[✓ -0.5]	-0.6	-0.6	-0.6	-0.6	-0.5	NA
Plan Irregularity, P_{L1}		-1.3	-1.2	-1.1	-0.9	-0.8	-1.0	-0.8	-0.7	-0.7	-0.9	-0.6	-0.8	-0.7	-0.7	-0.7	-0.5	NA
Pre-Code		-0.8	-0.9	-0.9	-0.5	-0.5	-0.7	-0.6	-0.2	-0.4	-0.7	-0.1	-0.4	-0.3	-0.5	-0.5	-0.1	-0.3
Post-Benchmark		1.5	1.9	2.3	1.4	1.4	1.0	1.9	NA	1.9	2.1	NA	2.1	2.4	2.1	2.1	NA	1.2
Soil Type A or B		0.3	0.6	0.9	0.6	0.9	0.3	0.9	0.9	0.6	0.8	0.7	0.9	0.7	0.8	0.8	0.6	0.9
Soil Type E (1-3 stories)		0.0	-0.1	-0.3	-0.4	-0.5	0.0	-0.4	-0.5	-0.2	-0.2	-0.4	-0.5	-0.3	-0.4	-0.4	-0.3	-0.5
Soil Type E (> 3 stories)		-0.5	-0.8	-1.2	-0.7	-0.7	NA	-0.7	-0.6	-0.6	-0.8	-0.4	NA	-0.5	-0.6	-0.7	-0.3	NA
Minimum Score, S_{MIN}		1.6	1.2	0.8	0.5	0.5	0.9	0.5	0.5	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.2	1.4

FINAL LEVEL 1 SCORE, $S_{L1} \geq S_{MIN}$: 0.9

EXTENT OF REVIEW
Exterior: ☐ Partial ☐ All Sides ☐ Aerial
Interior: ☐ None ☐ Visible ☐ Entered
Drawings Reviewed: ☐ Yes ☐ No
Soil Type Source:
Geologic Hazards Source:
Contact Person:

LEVEL 2 SCREENING PERFORMED?
☐ Yes, Final Level 2 Score, S_{L2} ☐ No
Nonstructural hazards? ☐ Yes ☐ No

OTHER HAZARDS
Are There Hazards That Trigger A Detailed Structural Evaluation?
☐ Pounding potential (unless S_{L2} > cut-off, if known)
☐ Falling hazards from taller adjacent building
☐ Geologic hazards or Soil Type F
☐ Significant damage/deterioration to the structural system

ACTION REQUIRED
Detailed Structural Evaluation Required?
☐ Yes, unknown FEMA building type or other building
☐ Yes, score less than cut-off
☐ Yes, other hazards present
☐ No
Detailed Nonstructural Evaluation Recommended? (check one)
☐ Yes, nonstructural hazards identified that should be evaluated
☐ No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
☐ No, no nonstructural hazards identified ☐ DNK

Where information cannot be verified, screener shall note the following: EST = Estimated or unreliable data OR DNK = Do Not Know

Legend: MRF = Moment-resisting frame BR = Braced frame RC = Reinforced concrete SW = Shear wall URM INF = Unreinforced masonry infill TU = Tilt up MH = Manufactured Housing LM = Light metal FD = Flexible diaphragm RD = Rigid diaphragm

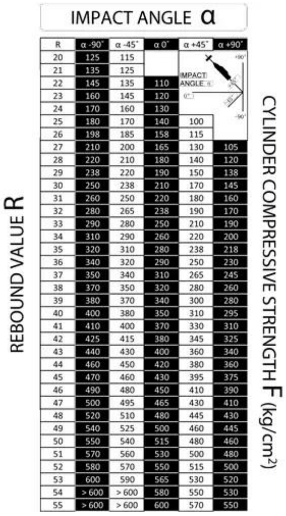
Fig. 1: Result of the FEMA P-154 form in the Galería Tradición

3.3. Schmidt Hammer Test

The selected building, being an old gallery without structural plans and lacking information on the concrete strength of its structural elements, was subjected to Schmidt hammer tests at various points on the structure's columns.

The procedure was carried out in accordance with ASTM C805, using a Schmidt-type rebound hammer, previously calibrated. Columns located on the first and second levels of the gallery were selected, on which a series of 10 to 12 impacts per point were applied, evenly distributed over the surface, discarding outlier values and calculating a representative average of the rebound index.

The values obtained were then correlated with empirical calibration curves provided by the equipment used, using the reference table from the PCE-HT-75 device.



IMPACT ANGLE α

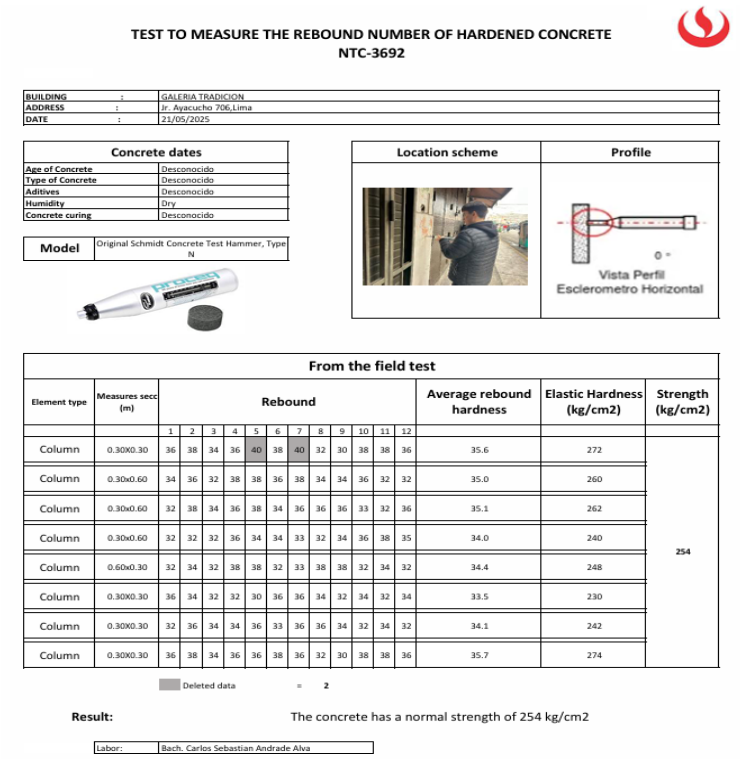
REBOUND VALUE R

CYLINDER COMPRESSIVE STRENGTH F (kg/cm²)

R	α -90°	α -45°	α 0°	α +45°	α +90°
20	125	115			
21	135	125			
22	145	135	110		
23	160	145	120		
24	170	160	130		
25	180	170	140	100	
26	198	185	158	115	
27	210	200	165	130	105
28	220	210	180	140	120
29	238	220	190	150	138
30	250	238	210	170	145
31	260	250	220	180	160
32	280	265	238	190	170
33	290	280	250	210	190
34	310	290	260	220	200
35	320	310	280	238	218
36	340	320	290	250	230
37	350	340	310	265	245
38	370	350	320	280	260
39	380	370	340	300	280
40	400	380	350	310	295
41	410	400	370	330	310
42	425	415	380	345	325
43	440	430	400	360	340
44	460	450	420	380	360
45	470	460	430	395	375
46	490	480	450	410	390
47	500	495	465	430	410
48	520	510	480	445	430
49	540	525	500	460	445
50	550	540	515	480	460
51	570	560	530	500	480
52	580	570	550	515	500
53	600	590	565	530	520
54	> 600	> 600	580	550	530
55	> 600	> 600	600	570	550

Fig. 2: Conversion table from rebound index to concrete strength – PCE-HT-75 Rebound Hammer

An average result of 254 kg/cm² was obtained, which was used as the concrete strength value for subsequent structural Modelling.



TEST TO MEASURE THE REBOUND NUMBER OF HARDENED CONCRETE
NTC-3692

BUILDING	:	GALERIA TRADICION
ADDRESS	:	Jr. Ayacucho 706,Lima
DATE	:	21/05/2025

Concrete dates	
Age of Concrete	Desconocido
Type of Concrete	Desconocido
Aditives	Desconocido
Humidity	Dry
Concrete curing	Desconocido

Model	Original Schmidt Concrete Test Hammer, Type N

Location scheme | **Profile**

From the field test

Element type	Measures secc (m)	Rebound												Average rebound hardness	Elastic Hardness (kg/cm2)	Strength (kg/cm2)
		1	2	3	4	5	6	7	8	9	10	11	12			
Column	0.30X0.30	36	38	34	36	40	38	40	32	30	38	38	36	35.6	272	254
Column	0.30x0.60	34	36	32	38	38	36	38	34	34	36	32	32	35.0	260	
Column	0.30x0.60	32	38	34	36	38	34	36	36	36	33	32	36	35.1	262	
Column	0.30x0.60	32	32	32	36	34	34	33	32	34	36	38	35	34.0	240	
Column	0.60x0.30	32	34	32	38	38	32	33	38	38	32	34	32	34.4	248	
Column	0.30X0.30	36	34	32	32	30	36	36	34	32	34	32	34	33.5	230	
Column	0.30X0.30	32	36	34	34	36	33	36	36	34	32	34	32	34.1	242	
Column	0.30X0.30	36	38	34	36	36	38	36	32	30	38	38	36	35.7	274	

▨ Deleted data = **2**

Result: The concrete has a normal strength of 254 kg/cm2

Labor:	Bach. Carlos Sebastian Andrade Alva

Fig. 3: Test to measure the rebound number of hardened concrete NTC-3692

3.4. Structural Modeling and Dynamic Analysis

This structure shares common characteristics such as intensive land use, the presence of reinforced concrete frame systems or mixed systems, and a high daily occupancy load, which increases its level of exposure to a seismic event.

As a complement to this preliminary evaluation, a building Galería Tradición was selected for structural modeling using ETABS software, with the objective of analyzing its dynamic behavior in greater detail under seismic events.

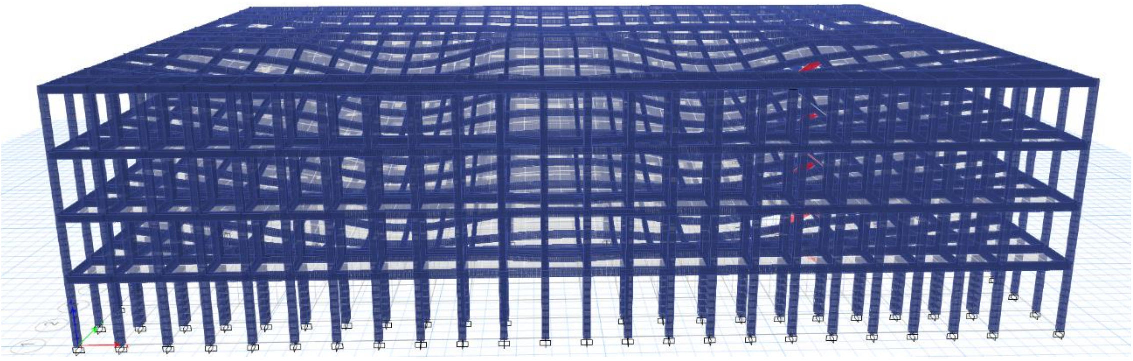


Fig. 4: ETABS Modeling of the Galería Tradición

The structure was subjected to a dynamic analysis using the four most representative seismic events recorded at the "Parque de la Reserva" accelerograph station, selected for time-history analysis in buildings. These earthquakes, recorded over the past century, include the 1966 earthquake (Mw 8.1), the 1970 earthquake (Mw 7.9), the 1974 earthquake (Mw 8.1), and another that occurred in November of the same year.

This seismic record was filtered and scaled to the uniform hazard spectrum with a reduction factor of 1 (R = 1), following the guidelines established in ASCE 7-10 Chapter 16.

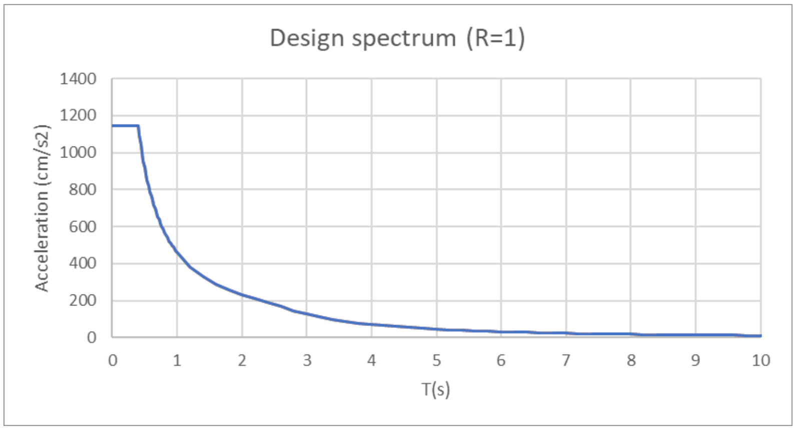
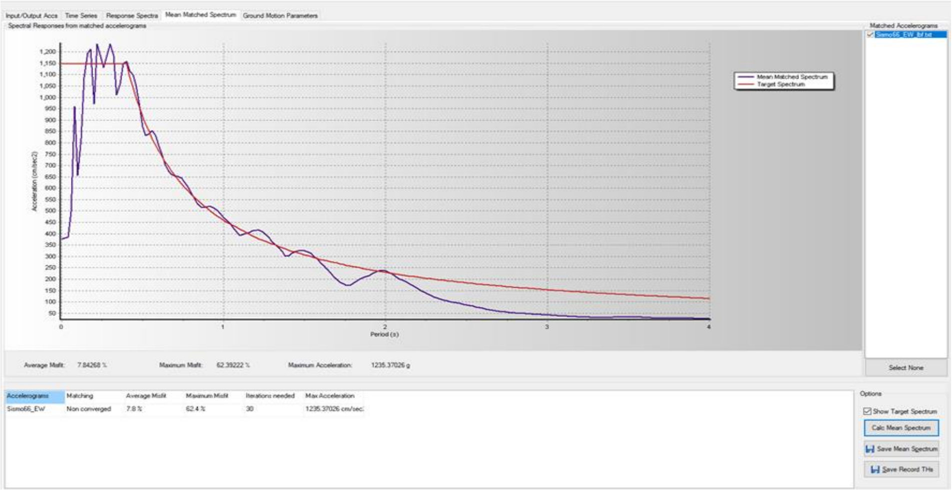


Fig. 5: Design Spectrum with a Reduction Factor Equal to 1

The results of the earthquake scaled to the design spectrum were obtained for the EW (East-West) and NS (North-South) components, which were used to evaluate the X-X and Y-Y axes, respectively



Average Misfit: 7.84268 %
Maximum Misfit: 62.39222 %
Maximum Acceleration: 1235.37026 g

Accelerograms	Matching	Average Misfit	Maximum Misfit	Iterations needed	Max Acceleration
Sismo66_EW	Non converged	7.8 %	62.4 %	30	1235.37026 cm/sec2

Fig. 6: Spectral Adjustment of the October 17, 1966 Earthquake

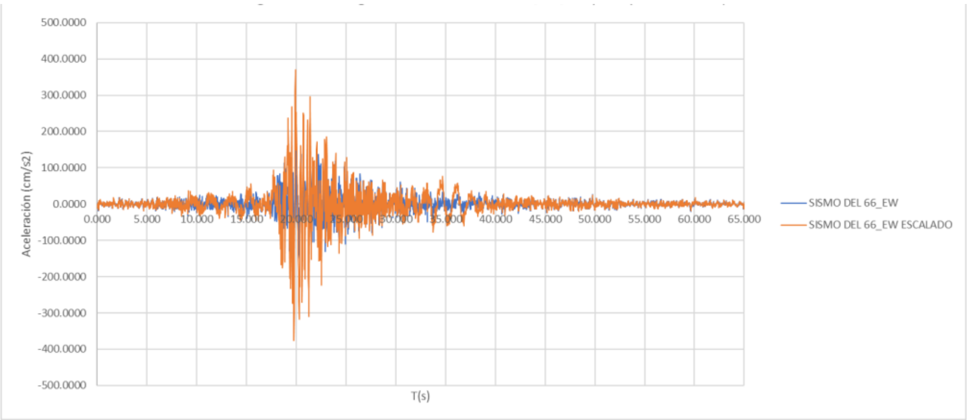


Fig. 7: Comparison of the Original and Scaled Accelerograph Records of the October 17, 1966 Earthquake (EW Component)

4. Results

A score of 0.9 was obtained in the FEMA P-154 form for the inspected gallery. In addition, the drift results from a dynamic analysis of each of the modeled structures subjected to 8 seismic records, corresponding to 4 seismic events divided into their EW and NS components were evaluated. These results were compared according to the provisions of the E.030 Seismic Design Code, which establishes a drift limit of 0.007 for structures primarily composed of reinforced concrete.

From the dynamic seismic analysis conducted on the structure to calculate its structural response to seismic excitations, the relative lateral displacement (drift) at each story was obtained. This can be expressed using the following equation:

$$\Delta = \frac{\delta_i - \delta_{i-1}}{h}$$

Where:

- Δ = Interstory Drift (dimensionless)
- δ_i, δ_{i-1} = Lateral displacement at floors i e i-1 respectively.
- h = Interstory height.

Table 1 shows the results of the drifts obtained after running the simulation of the scaled earthquake in the ETABS software.

Table 1: Drifts of the Gallery Subjected to the October 17, 1966 Earthquake

EARTHQUAKE OF 66						
Floor	**Displacement of C.M. in X (m)**	**Drift in X**	**E.030 Standard**	**Displacement of C.G. in Y (m)**	**Drift in Y**	**E.030 Standard**
4	0.02109	0.0011	**complies**	0.03708	0.00354	**complies**
3	0.01864	0.00203	**complies**	0.03023	0.00412	**complies**
2	0.014	0.00259	**complies**	0.02067	0.00445	**complies**
1	0.00775	0.00245	**complies**	0.00943	0.00314	**complies**

In addition to the derivation data, the program provides us with the following graph that represents the drifts on both axes

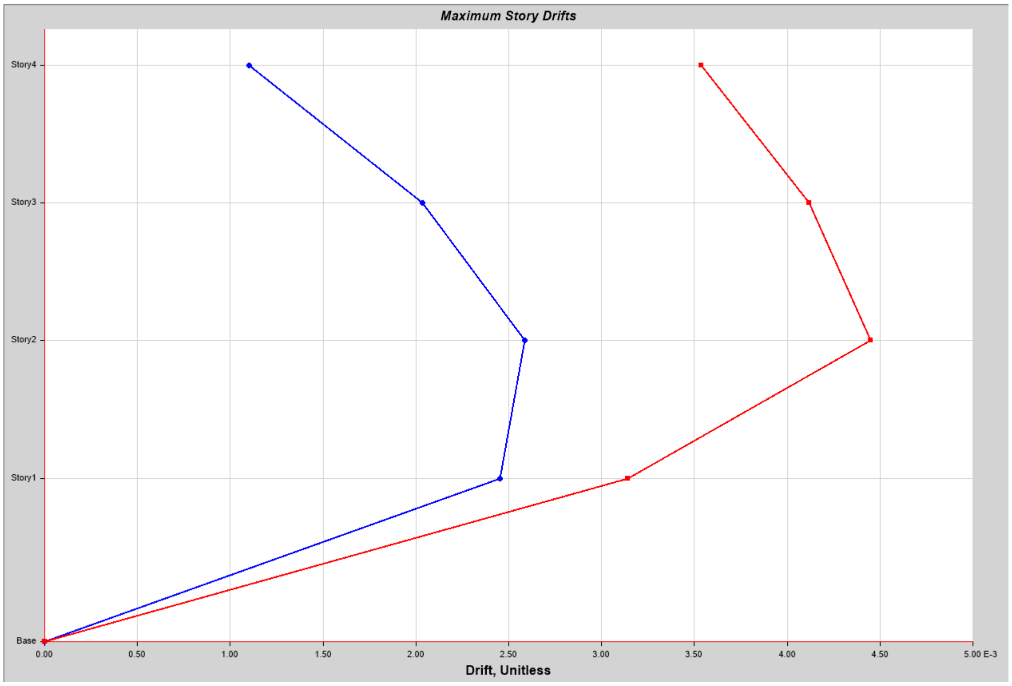


Fig. 8: Graph of the drifts obtained with the Etabs software

5. Conclusion

The structure analyzed demonstrated good seismic resistance according to the FEMA P-154 methodology, due to the absence of significant irregularities in its configuration. The score obtained, which is above the threshold established by the FEMA format, is mainly influenced by the lack of notable structural deficiencies.

Additionally, to validate the result provided by the FEMA P-154 method, a dynamic seismic analysis was performed using the ETABS software. This analysis confirmed that the interstory drifts, when subjected to seismic excitations, did not exceed the 0.007 limit established by the E.030 Seismic Design Code. Therefore, in the event of a major earthquake, the structure would not experience severe inelastic deformations, helping to ensure the safety of both the building and its occupants.

There is a clear consistency between the results obtained through the rapid visual inspection (FEMA P-154 Method) and the dynamic seismic analysis. Both methods indicate that the building exhibits good seismic performance, which reinforces the reliability of using these visual inspection tools as a preliminary filter for more detailed studies on buildings, whether they receive high or low scores.

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