Revista ALCONPAT
www.revistaalconpat.org
eISSN 2007-6835
Revista de la Asociación Latinoamericana de Control de Calidad, Patología y Recuperación de la Construcción

Characterization of failures and estimation of the qualitative seismic vulnerability of two reinforced concrete school buildings located in Falcón State.

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DOI: https://doi.org/10.21041/ra.v16i3.1098

Received: 04/03/2026 | Corrections received: 23/04/2026 | Accepted: 10/07/2026 | Published: 01/09/2026

ABSTRACT

The objective of this study was to characterize the structural failures and estimate the qualitative seismic vulnerability of two reinforced concrete school buildings located in Falcón State, Venezuela. The methodology employed included a visual inspection with photographic documentation of failures, environmental classification according to the NTF 4015:2012 standard, and determination of qualitative seismic vulnerability using the FUNVISIS method (Code FUN-002, 2014). The results showed that both schools are exposed to a chloride-corrosive environment (M4). The originality of this study lies in the application of the FUNVISIS method to school buildings in a marine environment. The seismic risk analysis revealed that one school exhibits high vulnerability (P5), while the second showed medium-low vulnerability (P8).
Keywords: corrosion; reinforced concrete; durability; preliminary diagnosis; seismic risk.

Citar como: Pérez, G. A., Rojas, D. C., Olavarrieta, M. A. (2026), *"Caracterización de fallas y estimación de la vulnerabilidad sísmica cualitativa de dos edificaciones escolares en concreto armado ubicadas en el Estado Falcón."*, Revista ALCONPAT, V (N), pp. 558 – 584, DOI: https://doi.org/10.21041/ra.v16i3.1098

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Author Contributions
In this work, author G. A. Pérez contributed to the original idea (10%), data collection (50%), experimental development (50%), discussion of results (40%), writing of the manuscript (50%), and review and editing of the manuscript (30%). Author D. C. Rojas contributed to the original idea (10%), data collection (50%), experimental development (50%), discussion of results (40%), writing of the manuscript (50%), and review and editing of the manuscript (30%). Author M. A. Olavarrieta contributed to the original idea (80%), discussion of results (20%), and review and editing of the manuscript (40%).

Discussions and Corrections after Publication
Any discussion, including the authors' reply, will be published in the third issue of year 2027, provided that the information is received before the closing of the second issue of year 2027.

Caracterización de fallas y estimación de la vulnerabilidad sísmica cualitativa de dos edificaciones escolares en concreto armado ubicadas en el Estado Falcón.

RESUMEN

El objetivo de este trabajo fue caracterizar las fallas y estimar la vulnerabilidad sísmica cualitativa de dos edificaciones escolares de concreto armado ubicadas en el estado Falcón, Venezuela. La metodología empleada incluyó una inspección visual con registro fotográfico de fallas, clasificación del ambiente según la Norma NTF 4015:2012, y determinación de la vulnerabilidad sísmica cualitativa mediante el método FUNVISIS (Código FUN-002, 2014). Los resultados mostraron que ambas escuelas están expuestas a un ambiente corrosivo por cloruros (M4). La originalidad radica en la aplicación del método FUNVISIS en edificaciones escolares en ambiente marino. El análisis de riesgo sísmico reveló que una escuela presenta vulnerabilidad elevada (P5), mientras que la segunda mostró vulnerabilidad media baja (P8).

Palabras clave: corrosión; hormigón armado; durabilidad; prediagnóstico; riesgo sísmico.

Caracterização de falhas e estimativa da vulnerabilidade sísmica qualitativa de dois edifícios escolares de concreto armado localizados no Estado Falcón.

RESUMO

O objetivo deste estudo foi caracterizar as falhas estruturais e estimar a vulnerabilidade sísmica qualitativa de dois edifícios escolares de concreto armado localizados no estado de Falcón, Venezuela. A metodologia empregada incluiu inspeção visual com documentação fotográfica das falhas, classificação ambiental de acordo com a norma NTF 4015:2012 e determinação da vulnerabilidade sísmica qualitativa utilizando o método FUNVISIS (Código FUN-002, 2014). Os resultados mostraram que ambas as escolas estão expostas a um ambiente corrosivo por cloretos (M4). A originalidade deste estudo reside na aplicação do método FUNVISIS a edifícios escolares em ambiente marinho. A análise de risco sísmico revelou que uma das escolas apresenta alta vulnerabilidade (P5), enquanto a segunda apresentou vulnerabilidade média-baixa (P8).

Palavras-chave: concreto armado; corrosão; durabilidade; pré-diagnóstico; risco sísmico.

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1. INTRODUCTION

Corrosion of reinforcing steel constitutes the main cause of premature deterioration of reinforced concrete, with especially critical consequences in coastal areas. Venezuela, and Falcón State in particular, faces this challenge acutely: its marine environment, with a high concentration of chloride ions, accelerates corrosion and compromises the structural safety of buildings (Porrero, 2014). The corrosion mechanism has a relative incidence of 20% among the pathological manifestations observed in reinforced concrete structures; it is an electrochemical phenomenon that is accelerated in the presence of aggressive agents, whether external and environmental or incorporated into the concrete mix (Helene P., 2007).
This problem is compounded in public educational institutions, whose preventive maintenance is usually insufficient or nonexistent, as established by the design manual of the Fundación de Edificaciones y Dotaciones Escolares, FEDE (Troconis and Fernández, 2007). Many of these buildings show a state of deterioration that makes them unsafe both for students and for use as emergency shelters. In addition, they fail to meet the durability requirements established in the Fondonorma Concrete Technical Standard, NTF 4015:2012 (Fondonorma, 2012). Given this reality, researchers at the Universidad Centroccidental "Lisandro Alvarado" have, for more than fifteen years, developed a research line aimed at characterizing the effects of aggressive environments on reinforced concrete in school buildings in Falcón State (Olavarrieta et al., 2017a; Olavarrieta et al., 2017b; Olavarrieta et al., 2020).
Regarding the qualitative assessment of seismic vulnerability, numerous methods have been proposed for different structural typologies; however, many present limitations related to the variables considered or the scope of their application. In this context, the FUNVISIS Prioritization Index method (López et al., 2014) is particularly relevant, as it incorporates variables such as local seismic hazard, structural vulnerability, and the importance of the building, allowing intervention hierarchies to be established expeditiously. The suitability of this method for school buildings, among the many qualitative methods available, was supported by Salas and Sierralta (2015) in their undergraduate thesis, which concluded that it was the methodology best suited to the characteristics of this type of building. The methodological contribution of this work consists of integrating the degree of corrosion-related deterioration, documented through a detailed preliminary inspection, as an input variable in the vulnerability subindex of the FUNVISIS method. This link between the actual physical condition of the buildings and their potential seismic behavior constitutes the originality of the study: it is not an isolated seismic vulnerability assessment, but rather an analysis that connects observed deterioration with intervention prioritization.
It is necessary to clarify the methodological scope of the study. What was carried out was a detailed preliminary inspection, which made it possible to document the symptomatology of the failures and characterize the exposure environment through visual observation, crack-width gauge and tape-measure readings, and systematic photographic recording. This level of inspection does not include specialized diagnostic tests, such as determination of carbonation, chloride content, electrical resistivity, compressive strength, corrosion potential, or thermography. The detailed preliminary inspection combined with the application of the FUNVISIS method, the subject of this article, constitutes a preliminary prioritization step that guides decision-making, but under no circumstances replaces it.
Consequently, the objective of this work is to assess the qualitative seismic vulnerability and establish the intervention prioritization of two reinforced concrete school buildings located in Silva Municipality, Falcón State, using the FUNVISIS Prioritization Index method (López et al., 2014), employing the failure characterization derived from the detailed preliminary inspection as an input for determining the degree of structural deterioration. This article is derived from an undergraduate engineering thesis (Pérez et al., 2022).

2. PROCEDURE

The study was carried out in three sequential phases: (i) detailed preliminary inspection of the buildings; (ii) characterization of the exposure environment; and (iii) calculation of the vulnerability, risk, and seismic prioritization indices according to the FUNVISIS methodology.
The first phase involved formal field visits to the selected institutions: the José Ramón Yépez National Bolivariana Primary School and the Armando Schwarck Anglade State Primary School. During these visits, preliminary meetings were held with school administrators to outline the research goals and secure inspection permits. General technical data were gathered, including official institutional name, geographical coordinates, construction year, original design use versus current occupancy, student enrollment, and maintenance history, adhering to the guidelines of the *Manual for Inspection, Evaluation, and Diagnosis of Corrosion in Reinforced Concrete Structures* (Troconis et al., 1997). Figure 1 shows a broad, general outline for the development of a diagnostic project for a reinforced concrete structure, from which all phases of the process derive, with the progress of each phase depending on the scope of the work. This research specifically began with the preliminary inspection, which includes visual examination of the structure and collection of background information on the buildings, without carrying out confirmatory tests or studies owing to the cost this would entail; nevertheless, the buildings were pre-diagnosed, after which the failure symptoms were surveyed, allowing their characterization and the formulation of possible hypotheses regarding their causes.
During the second visit, a planimetric survey of the buildings was carried out to identify their structural elements and subsystems. The systems inspected were classified as: structural, sanitary installations, roofing, façades, and surrounding areas. Simultaneously, the characterization of failures was carried out through visual inspection. This survey was performed in two complementary stages. In the first, the symptomatology of the failures was recorded using a crack-width gauge, a tape measure, and recording sheets, supported by photographs, giving priority to structural elements (beams and columns). Each symptom was assigned an identification code — for example: A1-1 for cracks, A1-2 for fissures, B2 for rust stains, C2-2 for concrete spalling — based on the DURAR Manual with in-house adaptations. In the second stage, each failure was documented on Form No. 2, recording: type of element affected, subsystem, location relative to the structural axes, sketch, photographs, description of extent and severity, and hypothesis of cause.

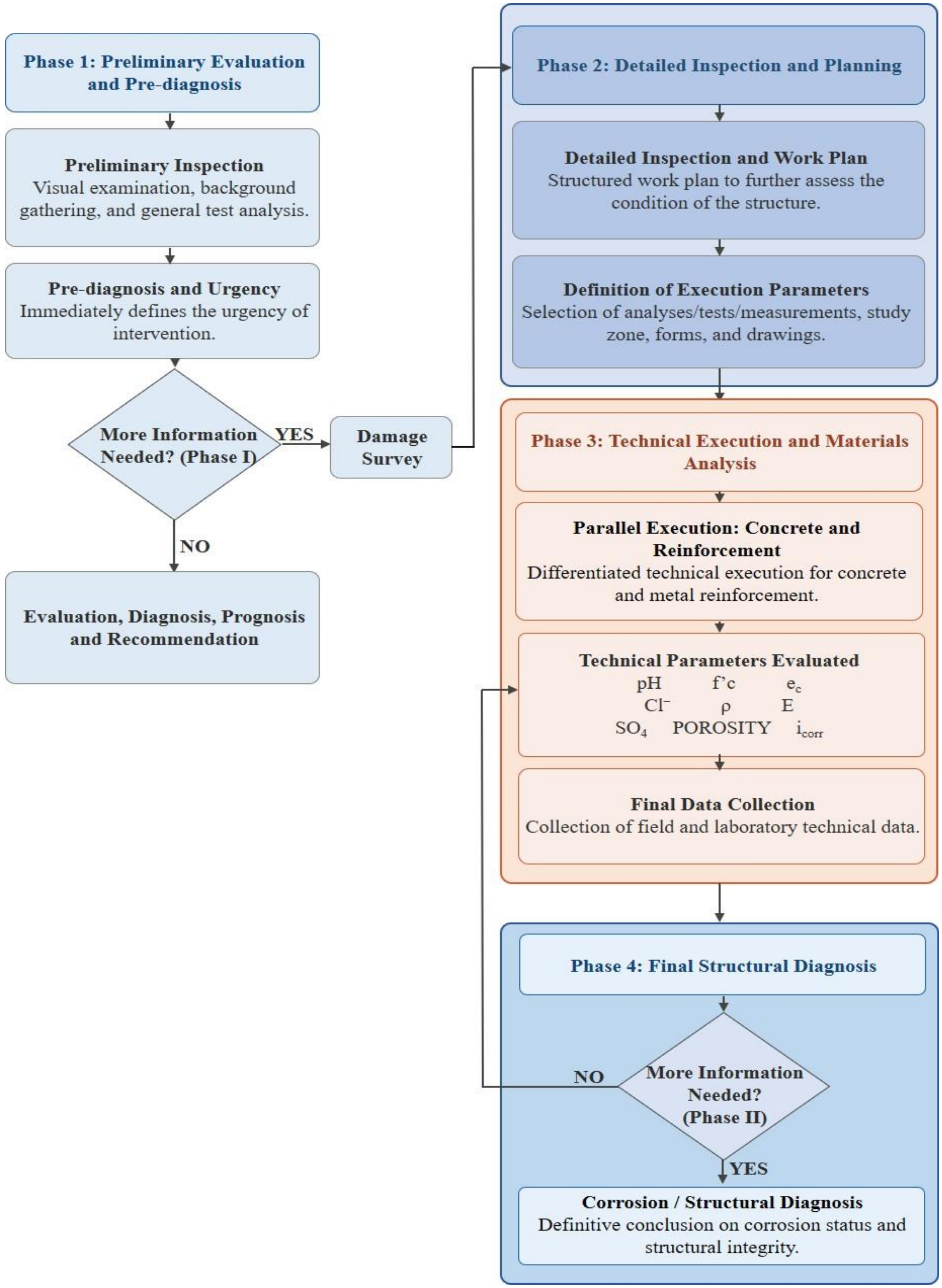


Figure 1. Methodological outline for the diagnosis of a reinforced concrete structure
Source: Troconis et al., 1997.

The characterization of failures was not limited to the visual survey; it also included identification, classification, location, quantification (length and thickness), and the formulation of origin hypotheses in accordance with the guidelines of the DURAR Manual. This process made it possible to establish the preliminary diagnosis of each building and its relationship to the deterioration mechanisms present. It is precisely the information obtained in this inspection that serves as the input for assigning the value of subindex I_6 (degree of deterioration), whose magnitude ranges from 0 — no deterioration — to 90 — severe deterioration with exposed reinforcing steel — and which has a direct bearing on the Vulnerability Index (I_v) and, consequently, on the final seismic prioritization.
The second phase consisted of characterizing the exposure environment of each structure using the table of exposure classes related to environmental conditions of standard NTF 4015:2012, which establishes limit values for aggressive agents, water/cement ratios, and concrete porosity criteria. The conditions of use of the structures subject them to physicochemical environmental actions with which they come into contact, which may include chemical actions, transport through porous materials, humidity variation, temperature variation, and expansive actions; all of these phenomena can lead the structure to a loss of performance and compromise its originally intended functions, that is, its functionality. Determining environmental variables therefore makes it possible to anticipate a possible evolution of the deterioration (Bertolini L., 2009).
The third phase corresponded to the calculation of the vulnerability, risk, and seismic prioritization indices, following the methodology established by FUNVISIS in the project *Prioritization Indices for Seismic Risk Management in Existing Buildings* (López et al., 2014). This methodology does not quantify vulnerability and risk levels in absolute terms; rather, it establishes priorities for decision-making aimed at determining which buildings most urgently require a more in-depth quantitative structural study.

3. ESTIMATION OF THE QUALITATIVE METHOD INDICES

For the qualitative analysis of seismic vulnerability, the equations presented below were used.

Building Prioritization Index:

$$I_P = I_A * I_V * I_I \qquad (1)$$

Where I_A is the hazard index, I_V is the vulnerability index, and I_I is the importance index. The hazard index can range between 0.05 and 1.00, the vulnerability index between 6.0 and 100, and the importance index between 0.80 and 1.00. The prioritization index can range between 1 and 100.

3.1 Hazard Index (I_A).

The hazard index incorporates peak ground acceleration on rock (A_o) assigned to Venezuela's seven seismic zones under standard COVENIN 1756-2001 (Fondonorma, 2021), as well as local topographic amplification factors. These values were taken from the Hazard Index value table proposed by López et al. (2014), as shown in Table 1.

Table 1. Hazard Index values. Source: Prioritization Indices for Seismic Risk Management in Existing Buildings, 2014.

Zone	**Seismic Hazard**	**Ao (Covenin 2001)**	**I_A**	
			Without topographic effects	**With topographic effects**
7	High	0.40	0.90	1
6		0.35	0.80	0.88
5		0.30	0.68	0.75
4	Intermediate	0.25	0.56	0.63
3		0.20	0.45	0.50
2	Low	0.15	0.34	0.38
1		0.10	0.23	0.25
0		-	0.05	0.05

The ground on which the schools are located, in Falcón State, is classified according to the COVENIN 1756-2001 (Fondonorma, 2021) standard as seismic zone 4 (peak ground acceleration Ao = 0.25 g), with no significant topographic effects, so $I_A = 0.56$ is assigned to both schools.

3.2 Vulnerability Index (I_v).

The Vulnerability Index (I_v) is given by:

$$Iv = \sum_{i=1}^{6} \alpha_i \cdot I_i \qquad (2)$$

Where I_i is the specific vulnerability index and α_i its relative weight; these are given in Table 2, Specific vulnerability indices (I_i) and relative weights (α_i). Each subindex captures a different dimension of structural vulnerability and is determined from visual inspection, without the need for advanced structural analysis.

The first subindex, I_1, reflects the age of the construction and the design standard used at the time it was built, assigning higher values to buildings predating modern seismic-resistant regulations. The second, I_2, corresponds to the predominant structural type, differentiating systems with greater or lesser capacity for energy dissipation during a seismic event. The third, I_3, penalizes the presence of geometric irregularities or structural deficiencies detected visually, such as short columns, soft stories, or pounding between adjoining modules, calculated as the sum of the sub-indices associated with each identified irregularity, with a maximum value of 100. The fourth, I_4, accounts for the increased vulnerability of multi-story buildings founded on deep sediment deposits. The fifth, I_5, incorporates the influence of ground topography and the absence of drainage systems. Finally, the sixth, I_6, quantifies the degree of deterioration observable in the structural elements, infill walls, and the general maintenance condition of the building. Each subindex is weighted by a coefficient α_i established in Table 2, reflecting its relative weight in overall vulnerability, with structural type ($\alpha_2 = 0.35$) and age ($\alpha_1 = 0.25$) being the factors of greatest influence (López et al., 2014). Taken from Table 2.

Table 2. Specific vulnerability index and relative weights. Source: Prioritization Indices for Seismic Risk Management in Existing Buildings.

I_i	Vulnerability associated with:	α_i
I_1	Age and design code applied	0.25
I_2	Structural type	0.35
I_3	Irregularity	0.25
I_4	Depth of sediment deposit	0.07
I_5	Topography and drainage	0.04
I_6	Degree of deterioration	0.04

3.3 Importance Index (I_i).

The value of this index is taken from Table 3 based on the use of the building and the number of occupants, and its purpose is to include the effects of the building's use and the number of people (N) exposed at the time a seismic event occurs. Higher indices are assigned to essential buildings, such as health centers and schools that serve as temporary shelters in emergencies. For school buildings, this includes the total number of students, teachers, and administrative staff present at the school during regular operating hours.

Table 3. Importance index values (I_i). Source: Prioritization Indices for Seismic Risk Management in Existing Buildings, 2014.

Group	$N \leq 10$	$10 < N \leq 100$	$100 < N \leq 500$	$500 < N \leq 1000$	$N > 1000$
A1	0.90	0.92	0.95	0.97	1
A2	0.85	0.87	0.90	0.93	0.95
A3	0.80	0.82	0.85	0.87	0.90

For this work, both institutions are classified in Group A2 (educational buildings serving as temporary shelters), with an enrollment of between 100 and 500 people, which yields Ii = 0.90 in both cases.

3.4 Assessment of the vulnerability, risk, and prioritization indices.

Vulnerability is qualitatively defined as shown in Table 4, based on the value obtained for the Vulnerability Index.(I_v)

Table 4. Vulnerability Index assessment (I_v). Source: Prioritization Indices for Seismic Risk Management in Existing Buildings, 2014.

Vulnerability Rating	I_v Range of Values
Very High	$60 \leq I_v \leq 100$
High	$40 \leq I_v < 60$
Medium-High	$30 \leq I_v < 40$
Medium-Low	$20 \leq I_v < 30$
Low	$10 \leq I_v < 20$
Very Low	$0 \leq I_v < 10$

On the other hand, the risk index is obtained qualitatively as the product of the hazard (I_A) and vulnerability indices (I_v), and then looking up its value in Table 5. That is:

$$I_r = I_A \cdot I_v \quad (3)$$

Table 5. Risk index assessment (I_r). Source: Prioritization Indices for Seismic Risk Management in Existing Buildings, 2014.

Risk Rating	I_R Range of Values
Very High	$60 \leq I_R \leq 100$
High	$40 \leq I_R < 60$
Elevated	$25 \leq I_R < 40$
Medium-High	$15 \leq I_R < 25$
Medium-Low	$8 \leq I_R < 15$
Low	$3 \leq I_R < 8$
Very Low	$0 \leq I_R < 3$

Finally, a qualitative assessment of the Prioritization Index is obtained using the criteria presented in Table 6.

Table 6. Assessment of the prioritization indices (I_p). Source: Prioritization Indices for Seismic Risk Management in Existing Buildings, 2014.

Prioritization Rating	I_P Range of Values
P1 (Maximum priority)	$60 \leq I_P \leq 100$
P2	$50 \leq I_P < 60$
P3	$40 \leq I_P < 50$
P4	$30 \leq I_P < 40$
P5	$25 \leq I_P < 30$
P6	$20 \leq I_P < 25$
P7	$16 \leq I_P < 20$
P8	$12 \leq I_P < 16$
P9	$8 \leq I_P < 12$
P10	$5 \leq I_P < 8$
P11	$2 \leq I_P < 5$
P12 (Minimum priority)	$0 \leq I_P < 2$

Following this procedure, the indices were calculated for all modules of both schools; the results are presented in the Analysis of Results section.

4. RESULTS ANALYSIS

4.1 José Ramón Yépez National Bolivariana Primary School.

The school is located in the Boca de Aroa parish, Silva Municipality, Falcón State, approximately 400 m from the coast (Figure 2). It was built in 1954. It began operating on October 1, 1956.

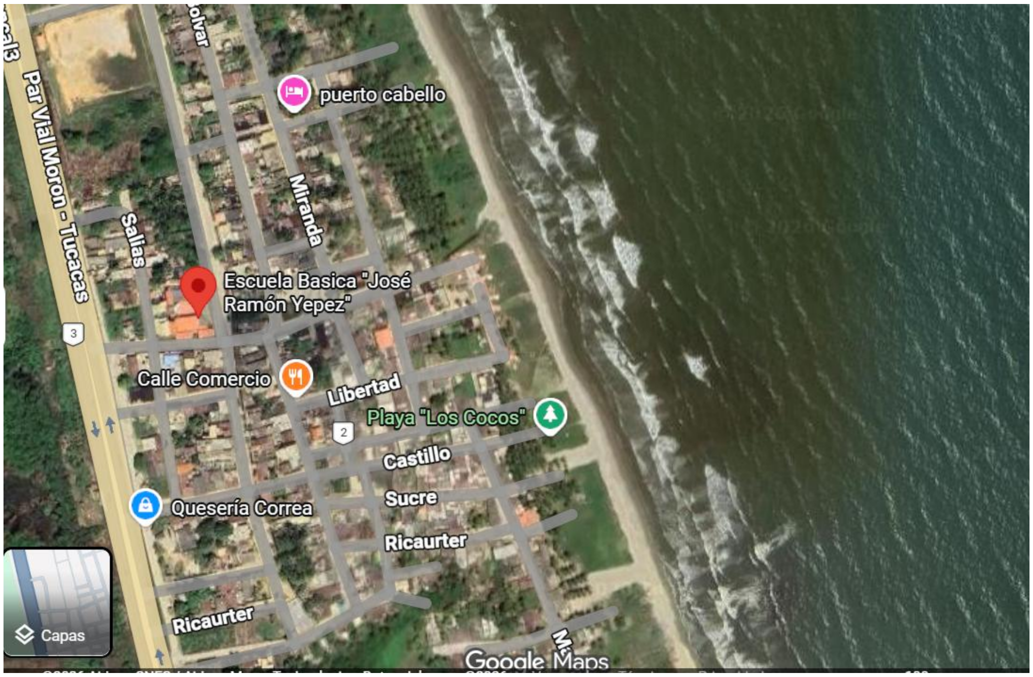


Figure 2. Satellite image of the José Ramón Yépez National Bolivariana Primary School
Source: Google Earth, 2021.

The institution comprises fifteen (15) classrooms, of which only eight (8) were operational. At the time, it had an enrollment of 246 students, 9 teachers, 4 maintenance workers, and 5 cooks. The structure is a reinforced concrete frame system. The windows and doors are covered with metal security bars (grilles). Additionally, during the 2007 renovation, the doors and windows throughout the institution were replaced; ventilation blocks were replaced with panoramic windows, and asbestos roofing was replaced with tongue-and-groove roofing on metal and, in some cases, wooden purlins. There are also surrounding areas with sidewalks and a perimeter wall that fully encloses the area occupied by the school. For the purposes of this study, the institution was divided into 8 modules. It is known that in 2009 seismic movements were recorded in the Boca de Aroa area, with an epicenter in Morón; the personnel interviewed stated that after this event, various failures appeared in walls and floors, mainly fissures and cracks.

4.1.1 Characterization of failure symptomatology.

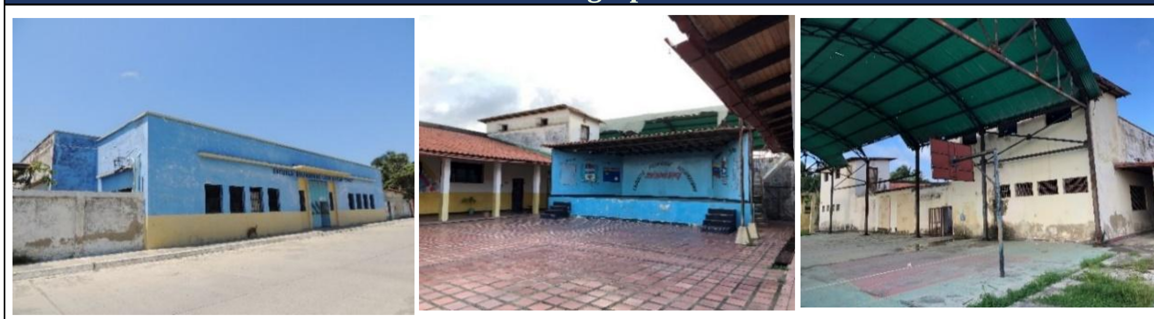
Once the survey of failure symptomatology was carried out, the most frequently occurring failures were identified. Figures 3 through 6 present the structure's visual inspection form and the most representative symptomatology forms for the damage observed in Module 1. These forms record, for each failure: its location on the sketch (distinguishing north orientation and the direction of the sea), its extent or severity, its description and characterization, and the probable hypothesis of its cause. This level of detail was maintained on all forms prepared for each module, whose complete data are presented in the appendices of the original undergraduate thesis (Pérez et al., 2022).

VISUAL INSPECTION FORM OF THE STRUCTURE

Name of Institution: José Ramon Yépez	**Year of Construction:** 1954
Location: 100m from troncal 3, Calle Piar between José Ramón Yépez and Salías.	**Inspection Date:** 01-March-2021, 02-March-2021 and 23-July-2021
Structure Type: Reinforced Concrete Frame	**No. of Floors:** 2

Sketch of the Area Under Study

Photographs



Failures Observed	Extent and Severity of the Failures
Fissures and Cracks Moisture stains Concrete spalling Plaster/render detachment Rust stains Exposed reinforcing steel Delaminated steel Cover thickness less than 0.5cm	The failures found most frequently were fissures and cracks in structural elements and enclosure walls, followed by moisture stains on enclosure and perimeter walls. Rust stains, concrete spalling, and delamination of reinforcing steel in structural elements. Failure in roof purlins.

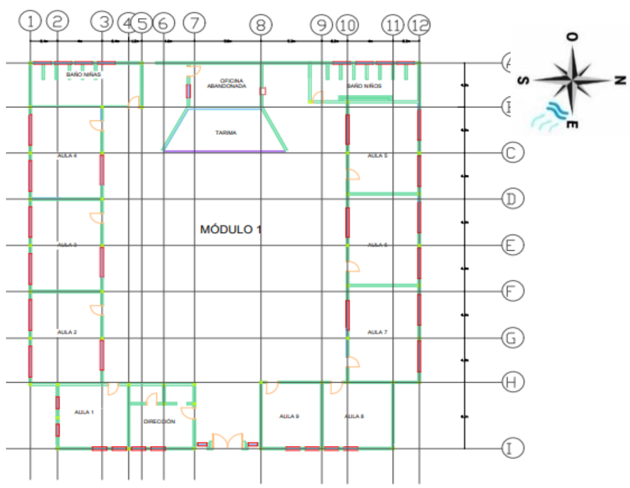
Prepared by: Pérez Gabriela, Rojas Daniela.

Figure 3. Visual Inspection Form of the José Ramón Yépez school
Source: Prepared by the authors (Pérez et al., 2022).

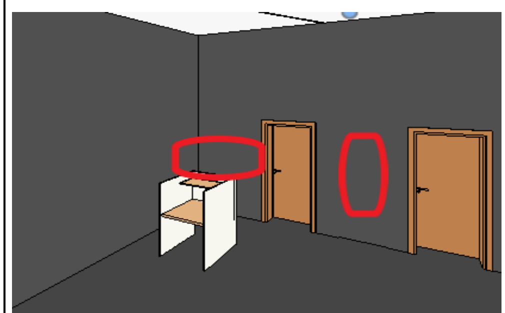
FAILURE SYMPTOMATOLOGY FORM

Name of Institution: José Ramon Yépez	**Form No.:** 5/23
Location: 100m from troncal 3, Calle Piar between José Ramón Yépez and Salías.	**Module:** 1
Structure Type: Reinforced Concrete Frame.	**Element Type:** Wall
Year of Construction: 1954	**Subsystem:** Enclosure

Sketch of the Area Under Study



Drawing of the Element



Photographs

1

2

Description of the Failure

Moisture, efflorescence, and bulging of the render are observed in the lower third of all enclosure walls in this direction. Detachment of the main coating (paint) is also observed.

Hypothesis

It is presumed that the moisture present is due to capillary effects caused by the rise of water contained in the foundations toward the structure through the pores of the slab concrete, the blocks, and the render itself, releasing salts and leaving white stains.

In addition, in the specific case of the enclosure wall located between axes H-I and 4-6 (photo 1), there is a possible leak caused by the sanitary installations of the adjacent bathroom.

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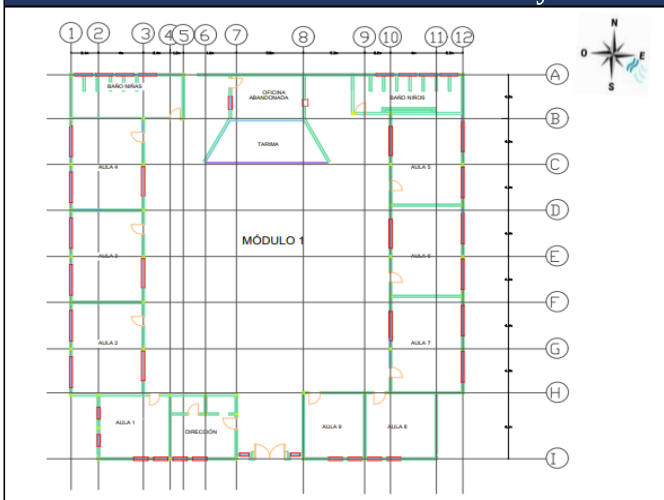
Figure 4. Failure Symptomatology Form. Module 1. 1/3
Source: Prepared by the authors (Pérez et al., 2022).

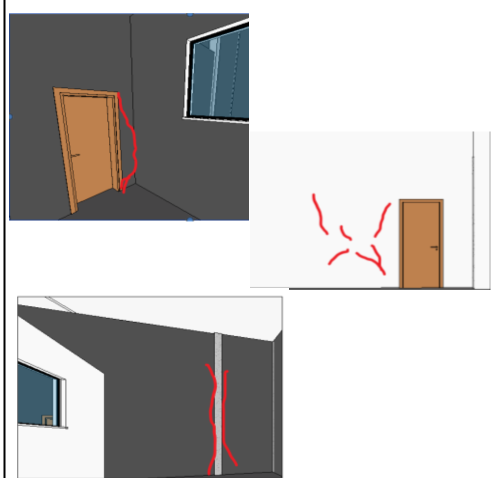
FAILURE SYMPTOMATOLOGY FORM

Name of Institution: José Ramon Yépez	**Form No.:** 6/23
Location: 100m from troncal 3, Calle Piar between José Ramón Yépez and Salías.	**Module:** 1
Structure Type: Reinforced Concrete Frame.	**Element Type:** Wall
Year of Construction: 1954	**Subsystem:** Enclosure

Sketch of the Area Under Study



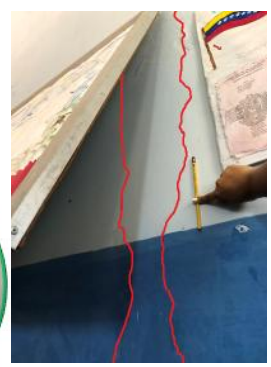
Drawing of the Element



Photographs

1

2



3

Description of the Failure

Concrete bulging is observed, in addition to:

1. Crack in the external enclosure wall of classroom 1, marked in red, located on axis H between axes 3-4. The crack starts at the upper left corner of the door frame, with a length of 1.24 m and a thickness of 0.05-0.70-0.80mm down to the yellow coating. It continues to the lower edge of the door frame with a length of 1.31m and a thickness > 2mm.

2. Cracks in the enclosure wall on axis H between axes 1-4, marked in red, on both the classroom 1 side and the classroom 2 side. In classroom 2, two cracks are visible: one located in the central third of the enclosure wall, 0.70 m long and more than 2mm thick. The second begins at the top of the enclosure wall with a length of 2.52 m and thicknesses of 0.10-0.08-0.60-0.50-0.30-1.50mm.

3. Various cracks and fissures, marked in red, on the internal enclosure wall of classroom 1, located on axis H between axes 3-4.

Hypothesis

It is presumed that the "X"-shaped cracks originated from the seismic movements that occurred in 2009.

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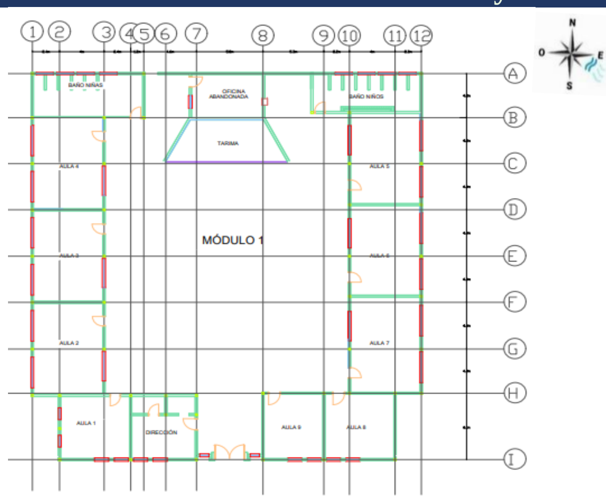
Figure 5. Failure Symptomatology Form. Module 1. 2/3
Source: Prepared by the authors (Pérez et al., 2022).

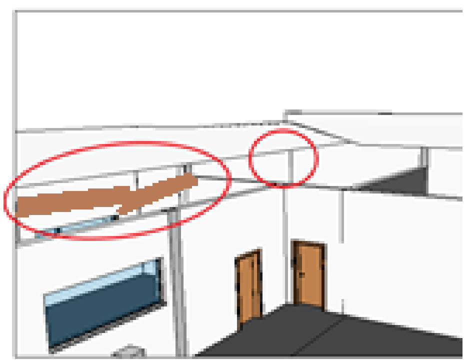
FAILURE SYMPTOMATOLOGY FORM

Name of Institution: José Ramon Yépez	**Form No.:** 7/23
Location: 100m from troncal 3, Calle Piar between José Ramón Yépez and Salías.	**Module:** 1
Structure Type: Reinforced Concrete Frame.	**Element Type:** Roof Slab
Year of Construction: 1954	**Subsystem:** Roof Covering

Sketch of the Area Under Study



Drawing of the Element



Photographs

1

2

3

4

Description of the Failure

The following is observed on all the tongue-and-groove roofs of the classrooms in Module 1:
-Moisture stains across the entire roof covering
-Detachment of the wooden roof purlins
-Rust stains on the metal roof purlins
-Loose electrical cables, without protection or covering
On the roof of classroom 7 (photo 4), breaks are observed in the wooden roof purlins. The ceiling support structure also shows detachment, and rust stains are visible.

Hypothesis

It is presumed that the moisture stains and the detachment of the tongue-and-groove boards are due to rainwater pooling on the roof covering, probably caused by deterioration of the waterproofing material from lack of maintenance.
-The roof purlins of classroom 7 may be broken due to having been subjected to overloads at certain points.

Prepared by: Pérez Gabriela, Rojas Daniela.	**Inspection Date:** 02-March-2021

Figure 6. Failure Symptomatology Form. Module 1. 3/3
Source: Prepared by the authors (Pérez et al., 2022).

Throughout the institution, a total of 160 failures were recorded during the inspection, as shown in Figure 7. The results were analyzed using a Pareto Diagram, also known as the 80-20 Method, which reflects the main failures found in Module 1 of the José Ramón Yépez school. This diagram is highly useful for pinpointing the main causes of problems, ranking them from highest to lowest frequency of occurrence, so that those requiring the most attention can be addressed first.

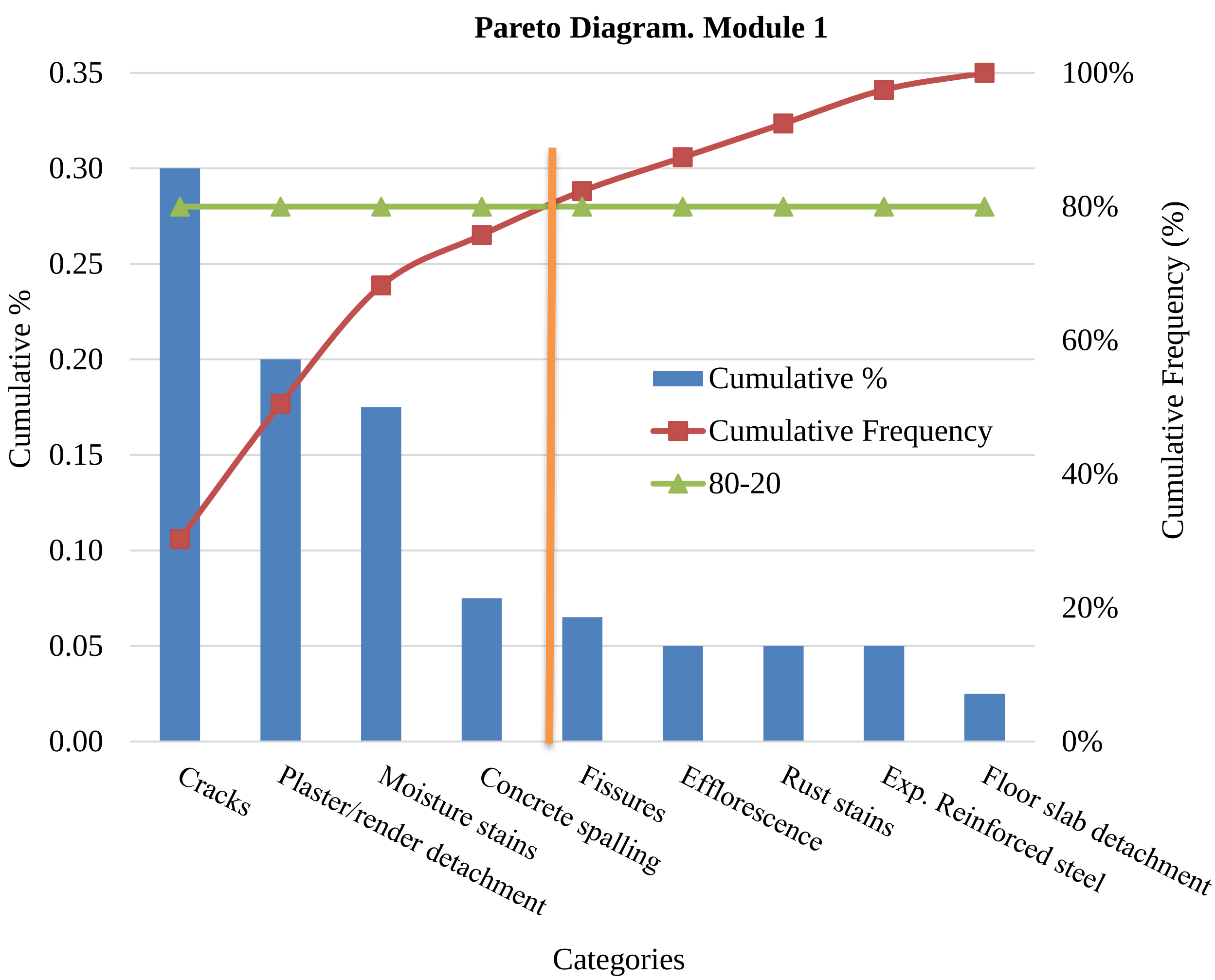


Figure 7. Pareto Diagram of the José Ramón Yépez school, Module 1.
Source: Prepared by the authors (Pérez et al., 2022).

The diagram shows that 80% of the failures correspond to cracks, plaster/render detachment, moisture stains, and concrete spalling. Cracks in structural elements are mainly associated with corrosion caused by chloride ion attack; this assumption is supported by the marine environmental classification and by the characteristic orientation of the cracking along the direction of the reinforcing steel. This mechanism begins with surface bulging caused by rust products; upon chloride attack, the passive layer is broken and the steel corrodes, initially producing a fissure, then a crack, followed by expansion of the concrete and complete exposure of the bar at the surface. The significance of the extent of cracking in relation to durability depends largely on whether the cracks follow the same direction as the reinforcing bar, particularly from a corrosion standpoint, since they can also reduce bond strength and shear resistance (Beeby A., 1993); other cracks appeared following the replacement of doors, grilles, and windows in 2007, or as a result of bending stresses in elements lacking nearby supporting columns. Moisture stains on enclosure walls are attributed to the absence of stormwater drainage systems and to damage in the piping. Plaster/render detachment, in turn, is linked to persistent dampness in the walls and to the development of corrosion processes in the reinforcing steel. It is worth noting that in two areas of the school, overlapping roof coverings were observed; although this condition can initially be classified as a construction defect, it generates more serious problems over time and increases the module's seismic vulnerability.

4.1.2 Characterization of the environment.

According to data provided by the Instituto Nacional de Meteorología e Hidrología (INAMEH), 2011, the average annual temperature recorded in Silva Municipality, Falcón State, is 26.6 °C, and the average annual relative humidity is 70%. The predominant average hourly wind direction affecting the structure in this area is from the east throughout the year. The school under study is located less than 500 meters from the coast, which makes it susceptible to chloride-induced corrosion attack from the marine environment.
Taking all of this information into account, and using the Table of Exposure Classes Related to Environmental Conditions as a basis, the environment can be classified as Marine class, subclass "airborne zone with distances of 5 to 500 m from the coastline," the process type as "Chloride-Induced Corrosion," and, finally, the designation as M4 (exterior members of structures in the vicinity of the coastline — 5 to 500 m) in accordance with the guidelines of the FONDONORMA NTF 4015:2012 Concrete Durability Technical Standard (Fondonorma, 2012).

4.1.3 Calculation of the building prioritization index for seismic risk management.

The school studied is located in seismic zone 4 according to the COVENIN 1756-2001 (Fondonorma, 2021) standard (Ao = 0.20 g), with no relevant topographic effects, so $I_A = 0.56$ is assigned (Table 1).
To calculate the Vulnerability Index, the following sub-indices were determined:

- $I_1 = 80$, as the building was constructed in 1954, prior to any Venezuelan seismic-resistant regulation.
- $I_2 = 40$, as it is a reinforced concrete frame system.
- $I_3 = 20$, owing to the presence of slab-against-slab pounding between the roofs of different modules.
- $I_4 = 0$ and $I_5 = 0$, as it is a single-story building on flat ground.
- $I_5 = 0$ as it is a construction on a plain with the presence of drainage systems.
- $I_6 = 90$, owing to the advanced state of deterioration observed during the visual inspection, which included exposed reinforcing steel and corrosion-induced cracking in structural elements.

Applying equation (2):

$$I_v = (80 * 0.25) + (40 * 0.35) + (20 * 0.25) + (0 * 0.07) + (0 * 0.04) + (90 * 0.04) \qquad (4)$$

$$I_v = 42.6 \qquad (5)$$

According to Table 4, a value of $I_v = 42.6$ corresponds to a vulnerability rated as High.
The school is classified in Group A2, with an enrollment of 246 students plus 18 staff members, within the range of 100 to 500 people, so $I_i = 0.90$ (Table 3).

With these values:
$I_r = 0.56 * 42.6 = 23.86$ (6) → Medium-High Risk (Table 5)
$I_p = 0.56 * 42.6 * 0.90 = 21.47$ (7) → Priority P6 (Table 6)

The same procedure was applied to the remaining eight modules.
The complete results for Module 1 are presented in Table 7.

Table 7. FUNVISIS method results for the José Ramón Yépez school.

Hazard Index (I_A)	0.56	
Vulnerability Index	**α_i**	**I_i**
Index associated with age (I_1)	0.25	80
Index associated with structural type (I_2)	0.35	40
Index associated with irregularities (I_3)	0.25	20
Index associated with sediment deposit depth (I_4)	0.07	0
Index associated with topography and drainage (I_5)	0.04	0
Index associated with degree of deterioration (I_6)	0.04	90
	I_v=	**42.6**
Importance Index (I_i)	0.90	
Risk Index (I_r)	23.86	
Risk rating	Medium-High	
Prioritization Index (I_p)	21.47	

The prioritization index value obtained (Ip = 21.47) is used to obtain the corresponding value for Module 1 of the school José Ramón Yépez. In this case, priority P6 was obtained.
Using the same procedure shown above, the remaining modules making up the institution (8 in total) were calculated. The module with the lowest prioritization index was Module 2, obtaining an index of P5. That is, it is the module with the most damage observed and the one that would require the most immediate attention.

4.2 Armando Schwarck Anglade State Primary School .
The Armando Schwarck Anglade State Primary School is located in Silva Municipality, Falcón State, approximately 1.5 km from the coast (Figure 8). It was founded in 2006. It has an enrollment of 386 students across primary, preschool, and daycare levels, and 16 teachers. It is a reinforced concrete structural system building, single-story, and is divided into 5 modules.

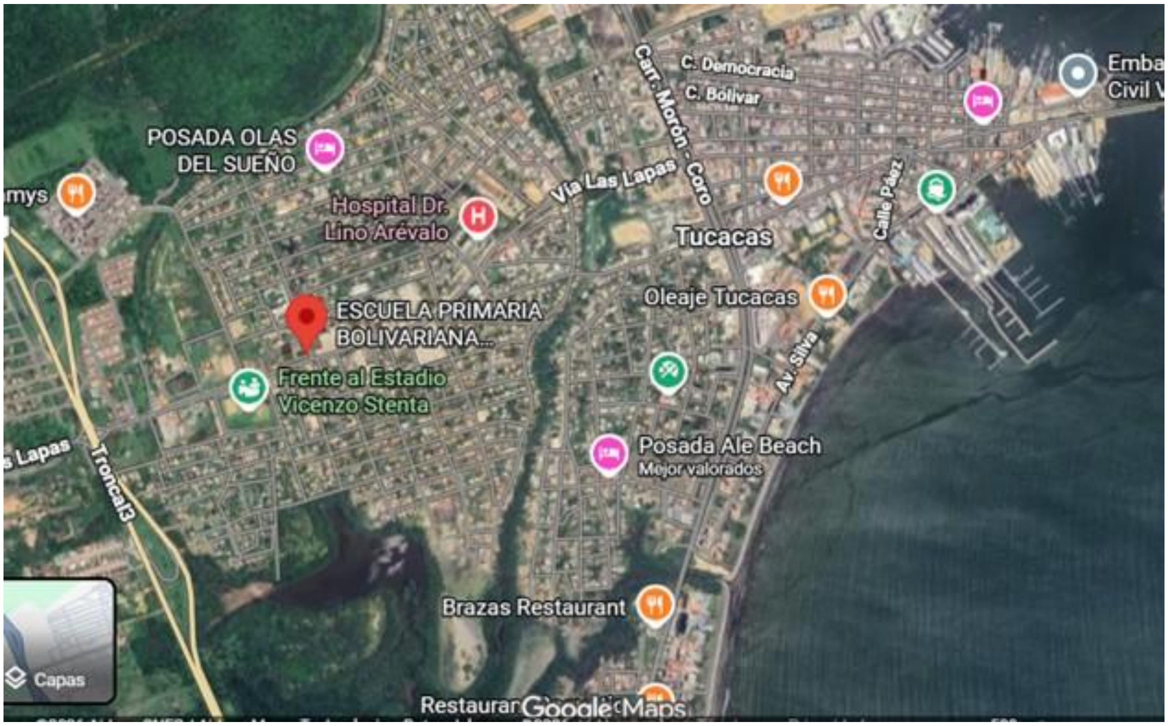


Figure 8. Satellite image of the Armando Schwarck Anglade State Primary School
Source: Google Earth, 2021

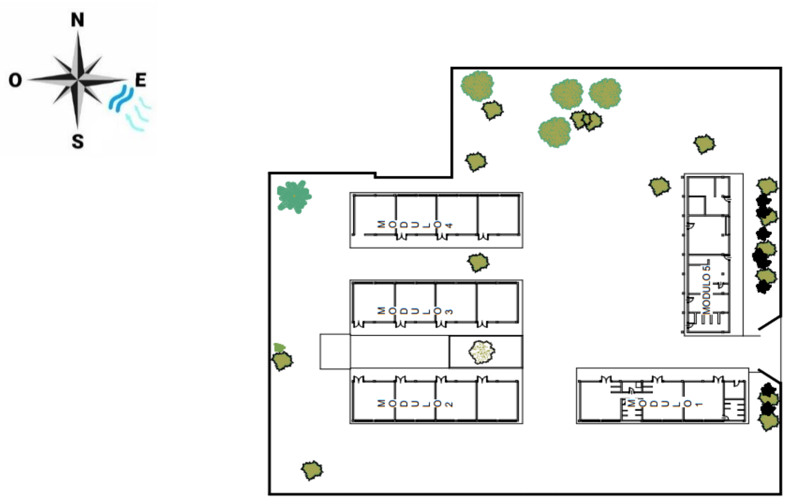
4.2.1 Characterization of failures.

Figures 9 through 12 present the visual inspection form and the most representative symptomatology forms for Module 4. During the inspection, 75 failures were identified at the institution. The most frequent were cracks (34 in total) and fissures (17). Also recorded were 11 moisture stains, 4 leaks, 4 instances of oxidation in metal frames, and, to a lesser extent: concrete spalling with exposed steel, a network of cracks, water pooling in walkways, localized exposure of reinforcing steel, floor slab detachment, and efflorescence. Failures predominated in enclosure elements.

VISUAL INSPECTION FORM OF THE STRUCTURE

Name of Institution: Armando Schwarck Anglade	**Year of Construction** : 2006
Location: Intersection of Calle Pedro Calles and Av. Principal Hugo Chávez Frías, Vía Las Lapas, Falcón.	**Inspection Date**: 04-March-2021 and 22-July-2021
Structure Type: Reinforced Concrete Frame.	**No. of Floors**: 1

Sketch of the Area Under Study



Photographs

Failures Observed	Extent and Severity of the Failures
Fissures and Cracks Moisture stains Plaster/render detachment Concrete spalling Leaks in the roof covering Exposed reinforcing steel	The failures found most frequently were fissures and cracks in enclosure walls, often at the joint between walls, windows, and doors, across all modules. Secondly, moisture stains on enclosure walls and leaks in the roof covering.

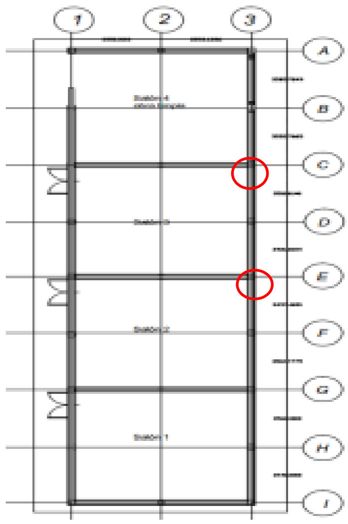
Prepared by: Pérez Gabriela, Rojas Daniela.

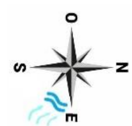
Figure 9. Visual Inspection Form of the Armando Schwarck Anglade Primary School
Source: Prepared by the authors (Pérez et al., 2022).

FAILURE SYMPTOMATOLOGY FORM

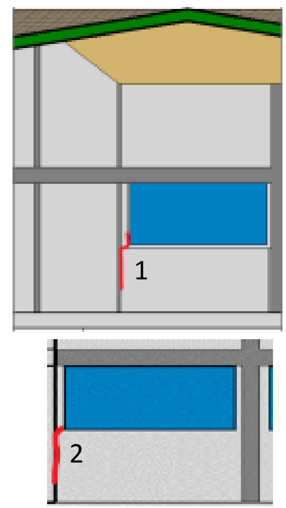
Name of Institution: Armando Schwarck Anglade	**Form No.**: 1/5
Location: Intersection of Calle Pedro Calles and Av. Principal Hugo Chávez Frías, Vía Las Lapas, Falcón.	**Module**: 4
Structure Type: Reinforced Concrete Frame	**Element Type**: Wall
Construction Date: 2006	**Subsystem**: Enclosure

Sketch of the Area Under Study





Drawing of the Element



Photographs

1

2

Description of the Failure

1. A vertical crack is observed on axis 3, between axes C-D, in classroom 2, module 4. The crack has widths of 0.70 mm at the top, 0.30 mm in the middle and lower sections. The length is 0.74 m.

2. A vertical crack is observed on axis 3, between axes G-H, in classroom 3, module 4. The crack has widths of 0.50 mm at the top, 0.10 mm in the middle and lower sections. The length is 0.98 m.

Hypothesis

It is likely that the fissure originated from structural movements, short-column effects, or the density differential between the block and column elements.

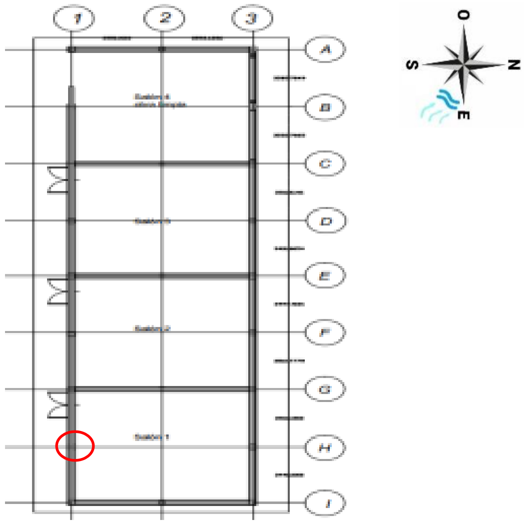
Prepared by: Pérez Gabriela, Rojas Daniela.	**Inspection Date**: 22-July-2021

Figure 10. Failure Symptomatology Form. Module 4. 1/3
Source: Prepared by the authors (Pérez et al., 2022).

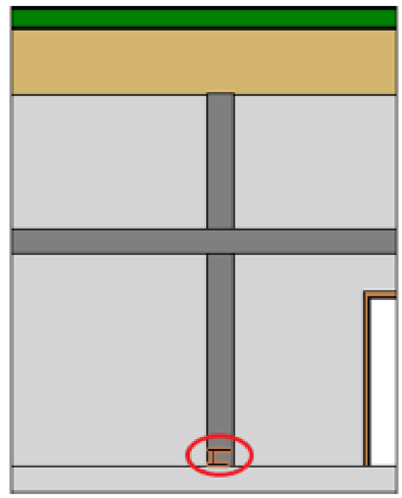
FAILURE SYMPTOMATOLOGY FORM

Name of Institution: Armando Schwarck Anglade	**Form No.**: 2/5
Location: Intersection of Calle Pedro Calles and Av. Principal Hugo Chávez Frías, Vía Las Lapas, Falcón.	**Module**: 4
Structure Type: Reinforced Concrete Frame.	**Element Type**: Column
Construction Date: 2006	**Subsystem**: Structural

Sketch of the Area Under Study



Drawing of the Element



Photographs

Description of the Failure

Concrete spalling and exposed reinforcing steel are observed in the column located on Axis 1-H in classroom 1, module 4. The classroom was not accessible; photos taken from the window. The approximate area of exposed steel is 0.40m x 0.15m = 0.06m^2

Hypothesis

It is presumed that the corrosion is due to the thin concrete cover thickness on the columns, combined with the aggressive environment to which the building is exposed.

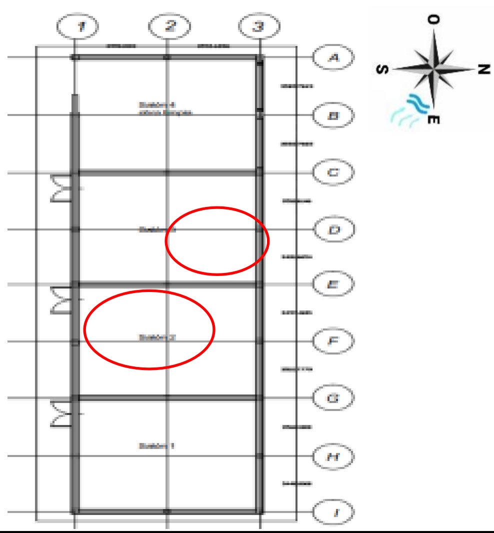
Prepared by: Pérez Gabriela, Rojas Daniela.	**Inspection Date**: 4-March-2021

Figure 11. Failure Symptomatology Form. Module 4. 2/3.
Source: Prepared by the authors (Pérez et al., 2022).

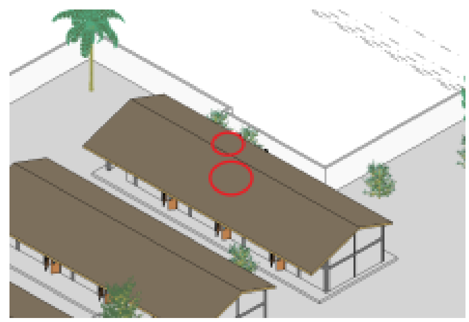
FAILURE SYMPTOMATOLOGY FORM

Name of Institution: Armando Schwarck Anglade	**Form No.**: 4/5
Location: Intersection of Calle Pedro Calles and Av. Principal Hugo Chávez Frías, Vía Las Lapas, Falcón.	**Module**: 4
Structure Type: Reinforced Concrete Frame.	**Element Type**: Roof Slab
Construction Date: 2006	**Subsystem**: Roof Covering

Sketch of the Area Under Study



Drawing of the Element



Photographs

Description of the Failure

1. Moisture staining is observed on the interior of the tongue-and-groove roof of classroom 3, module 4, located on axes 1-2 between axes C-D.
2. A black moisture stain is observed on the interior of the tongue-and-groove roof of classroom 2, module 4, located between axes F-G and 2-3.

Hypothesis

It is presumed that the moisture stains on the tongue-and-groove boards are due to the lack of a drip edge on the roof border to protect it from leaks. It is also possible that the waterproofing material was not extended far enough to cover the roof edge, causing water to seep between the waterproofing and the wood.

Prepared by: Pérez Gabriela, Rojas Daniela.	**Inspection Date**: 4-March-2021

Figure 12. Failure Symptomatology Form. Module 4. 3/3.
Source: Prepared by the authors (Pérez et al., 2022).

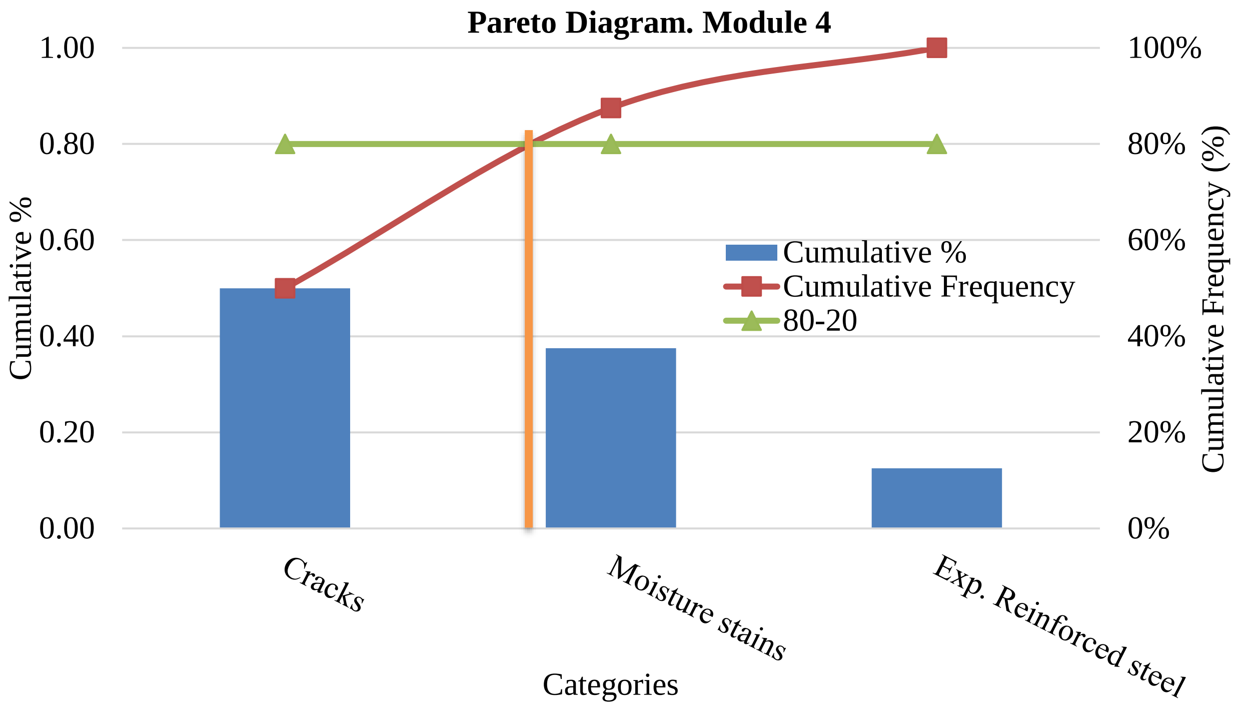


Figure 13. Failure Diagram of the Armando Schwarck Anglade Primary School, Module 4.
Source: Prepared by the authors (Pérez et al., 2022).

The Pareto diagram in Figure 13 shows that 80% of the failures correspond to: cracks and moisture stains, leaks caused by deficient roof waterproofing, moisture stains originating from potable water piping, absence of rainwater collection channels leading to water pooling and allowing the walls to become damp, oxidation on window and door frames caused by the ingress of chloride ions into the surrounding environment given that this building is exposed to an aggressive environment, and finally, concrete spalling generated by corrosion occurring in structural elements. This type of failure in the building, resulting from interaction with the environment, could be avoided through concrete mix designs with low water/cement ratios, sufficient cement content, and the use of admixtures, as well as careful placement and curing of the cast elements (Sanjuan M., Castro P., 2001).

4.2.2 Characterization of the environment.

The environment in which the school is located is very similar to that of the José Ramón Yépez school, as it is in the same municipality and close by, so similar environmental considerations were applied. The school is located between 1 and 1.5 km from the coastline; this classification is not available in the range specified by Technical Standard 4015:2012 Concrete Durability. However, it can be said that at this distance the building is subject to chloride-induced corrosion, being located less than 2,000 m from the sea, the range within which sea spray affects structures. Taking these considerations into account, the structure is classified as type M4 (marine class, exterior members of structures in the vicinity of the coastline — 5 to 500 m). Even though it falls outside this distance range, given the characteristics of its symptoms, the corrosion is chloride-induced rather than carbonation-induced.

This difficulty in classifying the environment according to its exposure serves as a comment for the NTF-4015 standard, in which it is suggested that an environmental exposure classification be added for marine classes located up to 2 km from the coast, the range within which sea winds can reach a structure significantly.

4.2.3 Calculation of the building prioritization index for seismic risk management.

For Module 4 of the Armando Schwarck Anglade school, taken as a representative case of the institution, the indices were assigned as follows.

The Hazard Index I_A = 0.56 is identical to that of the José Ramón Yépez school, as both are located in the same municipality and seismic zone (zone 4, Ao = 0.20 g, Table 1).

To calculate the Vulnerability Index I_v (equation 2), each subindex was determined as follows.

- The age index I_1 = 15 corresponds to a building constructed in 2006, after the COVENIN 1756-2001 (Fondonorma, 2021) seismic-resistant standard came into effect, so it is assigned the lowest value on the age table.
- The structural type index I_2 = 40 is the same as that of the José Ramón Yépez school, as it shares the reinforced concrete frame system with concrete block infill (Table 2).
- The irregularity index I_3 = 30 was assigned owing to the presence of short columns detected during the visual inspection, an irregularity that concentrates stresses during earthquakes and is especially concerning given that the building is recent.
- Index I_4 = 0 was assigned as it is a single-story building.
- Index I_5 = 20 was assigned owing to the absence of drainage channels in the module, a condition that increases vulnerability according to the corresponding table even though the ground is flat.
- Finally, the deterioration index I_6 = 50 reflects the condition of the module: cracking in structural elements with moderate-severity corrosion (subindex 35), moderate cracking in infill walls (subindex 10), and a fair overall maintenance condition (subindex 5).

Next, applying equation (2):

$$I_v = (15 * 0.25) + (40 * 0.35) + (30 * 0.25) + (0 * 0.07) + (20 * 0.04) + (50 * 0.04) \quad (8)$$

$$I_v = 28.05 \quad (9)$$

According to Table 4, a value of $I_v = 28.05$ corresponds to a vulnerability rated as Medium-Low. The Importance Index I_i = 0.90 is obtained from Table 3, as it is an educational building in Group A2 with an enrollment of between 100 and 500 people (386 students).

With these values, the Risk Index is:

$$I_r = 0.56 * 28.05 = 15.71 \quad (10) \quad \rightarrow \text{Medium-High Risk (Table 5)}$$

Finally, the Prioritization Index:

$$I_p = 0.56 * 28.05 * 0.90 \quad (11)$$

$$I_p = 14.14 \quad (12) \quad \rightarrow \text{Priority P8 (Table 6)}$$

The same procedure was applied to the institution's remaining modules, yielding the same priority level, P8, in all cases. The Module results are summarized in Table 8.

Table 8. FUNVISIS method results for the Armando Schwarck Anglade school.

Hazard Index (I_A)	0.56	
Vulnerability Index	**α_i**	**I_i**
Index associated with age (I_1)	0.25	15
Index associated with structural type (I_2)	0.35	40
Index associated with irregularities (I_3)	0.25	30
Index associated with sediment deposit depth (I_4)	0.07	0
Index associated with topography and drainage (I_5)	0.04	20
Index associated with degree of deterioration (I_6)	0.04	50
	Iv=	**28.05**
Importance Index (I_i)	0.90	
Risk Index (I_r)	15.71	
Risk rating	Medium-High	
Prioritization Index (I_p)	14.14	

In this way, the priority is established with which a more in-depth structural and seismic study should be carried out for Module 4 of the Armando Schwarck Anglade school according to the methodology applied, established in this case as priority P8, taking into account that the maximum priority is P1 and the lowest is P12.

5. CONCLUSIONS

The objective of this work was to assess the qualitative seismic vulnerability and establish the intervention prioritization of two reinforced concrete school buildings located in Silva Municipality, Falcón State. To this end, a detailed preliminary inspection was carried out combining the survey of failure symptomatology, characterization of the exposure environment, and application of the FUNVISIS Prioritization Index method (López et al., 2014). The main conclusions are presented below.

The predominant failures in both buildings were mainly: cracks, fissures, moisture stains, and detachments, with patterns associated with chloride-induced corrosion processes typical of marine environments.

At the José Ramón Yépez school, the deterioration is especially severe: proximity to the sea, the lack of stormwater drainage, and deficient maintenance — compounded by the 2007 construction modifications and the effects of the 2009 earthquake — have produced an advanced state of degradation that includes exposed reinforcing steel in structural elements. At the Armando Schwarck Anglade school, the failures are less severe in terms of structural elements, although their occurrence in a building constructed in 2006 shows that aggressive environmental conditions affect even recent construction.

Both institutions are located in a corrosive marine environment classified as M4 under standard NTF 4015:2012. Neither was built to the durability specifications this standard establishes for aggressive environments, which has negatively affected their state of conservation. In the case of the Armando Schwarck Anglade primary school, the distance to the coast (between 1 and 1.5 km) exceeds the range covered by the standard, which highlights the need to incorporate an exposure

subclass covering structures located up to 2,000 m from the coastline.
The originality of the study lies in having integrated the degree of corrosion-related deterioration, documented during the detailed preliminary inspection, as an input variable in subindex I_6 of the FUNVISIS method. This link between the actual physical condition of the buildings and seismic prioritization makes it possible to qualitatively reflect the effect of deterioration on structural vulnerability: although the relative weight of I_6 in the overall index is 0.04, its influence becomes decisive when deterioration reaches maximum values, as occurs in the most deteriorated modules of the José Ramón Yépez school.
Applying the FUNVISIS method, Modules 2 and 3 of the José Ramón Yépez school exhibit the greatest vulnerability and risk (priority P5, high vulnerability, high risk). This result is mainly explained by the combination of two factors: the age of the building (constructed in 1954, $I_1 = 80$) and the severe degree of deterioration observed ($I_6 = 90$, with exposed reinforcing steel in structural elements). This combination causes the vulnerability index I_V to exceed the threshold of the High category ($I_V > 40$), which, weighted by the zone 4 seismic hazard ($I_A = 0.56$) and the educational importance ($I_I = 0.90$), places the module at a high intervention priority.
In contrast, the Armando Schwarck Anglade school, built in 2006 under current seismic-resistant regulations ($I_1 = 15$), presents priority P8 (medium-low vulnerability) in all its modules even with moderate deterioration ($I_6 = 50$), reflecting the positive effect of regulatory compliance on seismic resistance. These differences reflect the combined weight of age, structural type, irregularities, and, especially, the degree of deterioration observed in each module.
It is essential to emphasize that this study has a strictly qualitative scope. The detailed preliminary inspection, while a valuable input for guiding decision-making and prioritizing interventions, does not replace a detailed inspection with laboratory testing (carbonation, chloride determination, electrical resistivity, compressive strength, corrosion potential, among others). Only on the basis of such a detailed inspection is it possible to issue a definitive, quantitative technical assessment of the structural condition of the buildings and to design the corresponding rehabilitation interventions.
In this regard, it is recommended that a detailed inspection be prioritized in the modules with priority P5, particularly Modules 2 and 3 of the José Ramón Yépez school, following the recommendations of Arrieta et al. (2013) regarding mix design characteristics for M4-type aggressive environments.
Finally, it is recommended that regulatory guidelines be established for assessing the qualitative vulnerability of buildings of national interest, explicitly considering that structures with advanced corrosion processes in their reinforcement will exhibit mechanical performance below that expected in the original design, which increases their actual vulnerability and seismic risk relative to values obtained by methods that do not incorporate the state of deterioration as a variable.

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