

Structural Pathology and Seismic Vulnerability in Community Infrastructure: The Case of the Women's Social Center in Cota, Colombia

Patología estructural y vulnerabilidad sísmica en infraestructura comunitaria: el caso del Centro Social de la Mujer en Cota, Colombia

Received: 22/08/2026; Reviewed: 05/09/2026; Accepted: 14/09/2026

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Abstract

This paper assesses the structural condition and vulnerability of the Women's Social Center, a single-story building with about 208 m² of floor area in Cota, Cundinamarca. The research, conducted under Contract SIOP-CM-006-2023, aims to assess the building's condition and verify the technical feasibility of vertical expansion, in accordance with the Colombian Code for Seismic-Resistant Construction (NSR-10). The meth-

odology comprised three phases during the first half of 2025: a direct visual inspection of the building and its surroundings; detailed photographic documentation and mapping of structural defects, damage, and deficiencies; and an experimental campaign using non-destructive and semi-destructive methods such as rebar scanning, concrete core sampling, trenching, foundation excavation, and geotechnical testing. Field data from mechanical and historical assessments informed mathematical modeling of the structure. Consolidating these results produced an etiological diagnosis that provides the basis and criteria for designing repairs, reinforcements, or modifications to safeguard the community infrastructure.

Keywords

Seismic vulnerability; structural pathology; non-destructive testing; NSR-10; structural retrofitting; infrastructure maintenance

Resumen

El presente artículo evalúa el estado estructural y la vulnerabilidad del Centro Social de la Mujer, una edificación de una sola planta con una superficie aproximada de 208 m² ubicada en Cota, Cundinamarca. La investigación, realizada en el marco del contrato SIOP-CM-006-2023, tiene como objetivo evaluar el estado del inmueble y verificar la viabilidad técnica de una ampliación vertical, de conformidad con el Reglamento Colombiano de Construcción Sismo Resistente (NSR-10). La metodología se desarrolló en tres fases durante el primer semestre de 2025: inspección visual directa del edificio y su entorno; documentación fotográfica detallada y levantamiento de defectos, daños y deficiencias estructurales; y una campaña experimental mediante métodos no destructivos y semidestructivos, tales como la detección de acero de refuerzo, la extracción de núcleos de concreto, la realización de calicatas, la excavación de cimentaciones y los ensayos geotécnicos. Los datos de campo, provenientes de evaluaciones mecánicas e históricas, sirvieron de base para el modelado matemático de la estructura. La consolidación de estos resultados permitió obtener un diagnóstico etiológico que proporciona los fundamentos y criterios para el diseño de reparaciones, refuerzos o modificaciones destinados a salvaguardar esta infraestructura comunitaria.

Palabras clave:

Vulnerabilidad sísmica; patología estructural; ensayos no destructivos; NSR-10; reforzamiento estructural; mantenimiento de infraestructura

Citation [IEEE]:

B. S. Plata-Jiménez and R. Martínez-Gutiérrez, "Structural pathology and seismic vulnerability in community infrastructure: The case of the Women's Social Center in Cota, Colombia," *J. Eng. Evol.*, vol. 2, pp. 34-65, XX 2026. doi

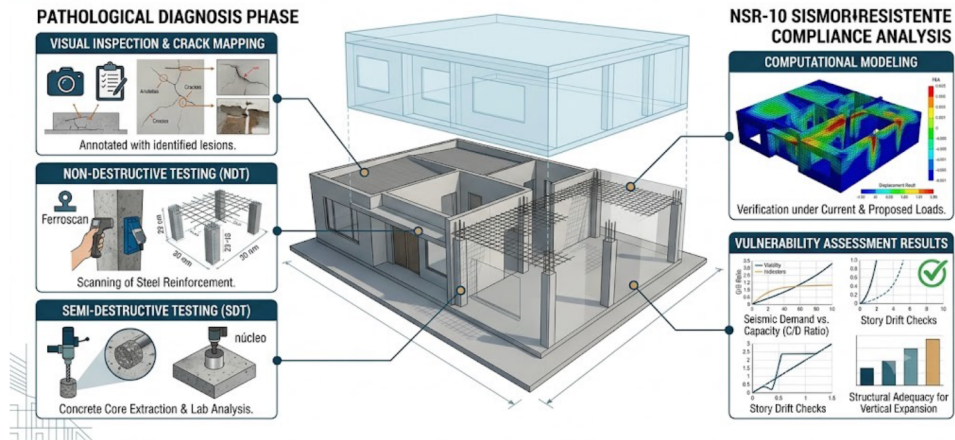
Introduction

This document presents a thorough, technically robust investigation of the infrastructural health and latent vulnerabilities of the Women's Social Center, a building distinguished not only by its utilitarian function within the community of Cota, Cundinamarca, but also by its architectural features and evolving role in the urban fabric. Executed under the auspices of Contract SIOP-CM-006-2023, this study adopts a multi-dimensional approach, combining detailed empirical observation, advanced structural forensics, and a holistic interpretation of context, history, and materiality. The diagnostic process develops through several connected stages: initial in-situ reconnaissance is carried out to gain a perceptive appreciation of the building's spatial logic, construction typology, and environmental setting; this is followed by an exhaustive photographic and written record of observed pathologies, ranging from superficial fissures and moisture ingress to slight anomalies in load-bearing elements.

The investigative sequence is further improved by the deployment of both non-destructive and semi-destructive tests—ferroscan surveys to map reinforcement, extraction of concrete cores for compressive strength assessment, targeted exploratory cuts (*regatas*), foundation pits (*apiques*), and geotechnical probes—each selected to illuminate specific uncertainties regarding material integrity and foundational behavior. All empirical data are compiled and then used as essential input for a mathematical modeling exercise, in which the structure's response to both routine and extraordinary actions, most notably seismic forces, is simulated in accordance with the most current national regulatory standards (NSR-10). The resulting synthesis is not limited to a catalog of technical findings; rather, it articulates a reasoned, integrated diagnosis that recognizes the relationships among design intent, construction practice, usage patterns, and the demands imposed by the building's civic function.

Based on these analyses, the document establishes a defensible technical baseline and a set of analytical criteria to support any proposed interventions—whether remedial, strengthening, or adaptive—and to ensure that the structural transformation—particularly the projected vertical expansion—is both feasible and prudent. Throughout, the narrative deliberately transcends formulaic engineering discourse, engaging instead with the broader implications of protecting a shared asset whose value exceeds the sum of its parts, thereby demonstrating a conscientious commitment to both technical merit and social stewardship (Figure 1).

Figure 1. Methodological Framework for the Structural and Seismic Evaluation of the Women's Social Center in Cota, Cundinamarca



Note. The diagram illustrates the integration of pathological diagnosis phases—including visual inspection, non-destructive testing (NDT), and semi-destructive testing (SDT)—with computational modeling for NSR-10 compliance analysis to assess the feasibility of vertical expansion.

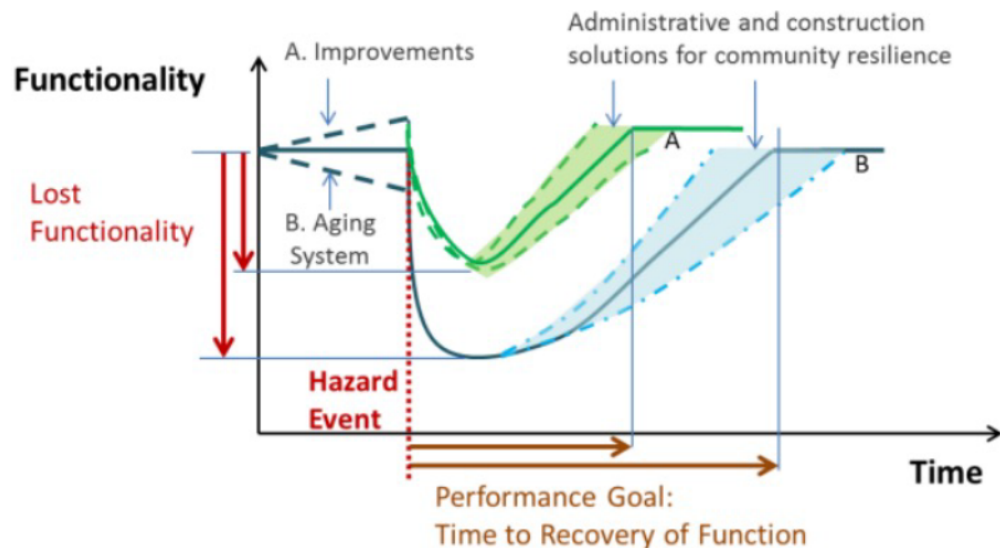
Community infrastructure systems are the foundation of modern urban societies. Yet, they remain highly susceptible to seismic hazards. Structural pathology involves detecting and describing deficiencies, deterioration, and damage in built systems. Its intersection with seismic vulnerability assessment is critical for guaranteeing community resilience. Seismic vulnerability assessments depend on different factors. These include topography, geology, seismicity, geotechnical site conditions, structural performance, lifelines, emergency services, and socioeconomic conditions [1]. This review summarizes the literature on how pathological conditions in community infrastructure interact with seismic vulnerability. It covers evaluation methodologies, impacts on critical systems, resilience frameworks, and risk reduction strategies. Urban planners can use these insights to prioritize maintenance of aging infrastructure, inform land-use policies, and develop emergency response plans that address identified vulnerabilities. By integrating structural pathology and seismic risk assessment into their planning processes, practitioners can make informed decisions that enhance community safety and resilience.

International Background

Seismic vulnerability refers to the likelihood that physical and social systems will be damaged by earthquakes. Seismic risk assessment is a necessary first step and a key component of implementing successful risk-reduction strategies [2]. For example, in the 2011 Christchurch earthquake in New Zealand, historic brick buildings without seismic retrofitting suffered severe damage. In contrast, newer buildings that followed updated codes fared better. This shows how different vulnerabilities can shape the effects of seismic events on communities. Risk is usually described as a combination of hazard, exposure, and vulnerability. Planning tools must include versatile strategies for exposure and vulnerability alleviation, especially for existing built heritage [3].

Physical infrastructure vulnerability includes buildings, transport infrastructure, water systems, electrical power systems, and other lifeline infrastructure. Often, these systems are not designed to resist hazards to the same degree, so they do not perform equally well [4]. Uneven design standards create different levels of vulnerability within infrastructure systems. This makes it more difficult to achieve community resilience. In practice, stronger elements in the built environment can become isolated weak points if other components are less robust. For instance, hospitals may be retrofitted, but if power or access roads are not, their emergency functions decline. This gap delays response and recovery, worsens the impacts of disasters on vulnerable groups, and raises long-term reconstruction costs. To build resilience, correct these design differences across all infrastructure systems [5] (see Figure 2).

Figure 2. Conceptual Framework for Resilience: Analysis of Functionality vs. Recovery Time to Evaluate the Performance of the Built Environment in the Face of a Disruptive Event [5]



Structural pathology refers to deficiencies, deterioration, and damage patterns that compromise the integrity of infrastructure. [6] explicitly address pathologies in structural systems, noting that “pathological deficiencies must be associated with the respective construction system, and the consequences of its exposure to external or internal agents. Those defects with less severe consequences are associated with a low degree of vulnerability. Pathologies that can compromise the stability of a building in the face of a seismic event are linked to higher degrees of vulnerability.” This direct link between structural pathology and seismic vulnerability underscores the importance of systematically identifying and classifying deficiencies.

For example, the collapse of the Alfred P. Murrah Federal Building in Oklahoma City in 1995 highlighted how pre-existing structural deficiencies, such as substandard concrete and undetected cracks, contributed to the scale of the destruction following the explosion. In seismic

zones, buildings in Mexico City after the 2017 earthquake showed how poorly maintained structures with existing cracks or corrosion were far more likely to sustain severe damage. Such real-world cases demonstrate the serious consequences of overlooking structural deficiencies.

[7] further detail the role of pathology detection in seismic risk management through VR/AR tools that drive users to “detect first the kind of cracks, fissures, or other pathologies present in a house and to relate them with a classifying guide.” In practice, these VR/AR tools immerse users in simulated or real-life visualizations of building elements, allowing them to virtually inspect surfaces, zoom in on potential defects, and work with digital overlays that display specific types of damage. This allows for more thorough, accessible inspections, supporting both training and field assessments without physical limitations. Their methodology also requires observers to identify secondary indicators such as “overgrown trees and shrubs, cracked drains, leaking rainwater goods, as some of the things that may result in structural problems but that are not related to the seismic inputs.” This complete approach to pathology identification, encompassing both seismic and non-seismic origins, reflects the multifactorial nature of infrastructure vulnerability.

Assessment Methodologies for Seismic Vulnerability

Contemporary seismic vulnerability assessment has evolved toward multi-criteria frameworks that integrate structural, geotechnical, and socioeconomic dimensions. [8] demonstrate that “assessing risk solely based on a single vulnerability criterion is inadequate” and advocate for considering multiple criteria, including seismic and geotechnical vulnerability together, as this reveals how ground conditions and earthquake hazards interact to amplify various types of vulnerabilities (Figure 3). Their GIS-AHP methodology assimilates both structural and non-structural vulnerability dimensions to support evidence-based policymaking [8]. The GIS-AHP approach unites Geographic Information Systems (GIS) with the Analytic Hierarchy Process (AHP), a structured decision-making method that assigns weights to criteria based on expert judgment, to spatially analyze and visualize vulnerability data. This procedure typically involves selecting relevant vulnerability factors, using AHP to determine the relative importance of each factor, and spatially mapping the results in GIS to provide a comprehensive assessment of seismic risk.

Similarly, [9] highlight the development of GIS-based platforms that incorporate well-established seismic risk and loss estimation methodologies to “quantify and visualize the damage state, the risk of significant damage as well as the direct economic loss of infrastructure systems in the aftermath of earthquakes.” Such platforms serve as decision-making tools for decision-makers, building owners, and insurance companies. However, these GIS-based platforms face several practical limitations. For example, the accuracy of risk assessments depends heavily on the quality and resolution of input data, which may vary across regions or be outdated. In addition, combining varied data sources and setting consistent criteria can cause challenges to comparability across studies. The complexity of the required analyses may also place demands on computing resources and require specialized expertise, possibly limiting extensive adoption.

Figure 3. Points of Interest in the Study Area: (a) Traditional Residential Area in Al-Khoud; (b) Modern Residential Complex in Al-Mouj; (C) Gas Station in the Densely Populated Urban Area of North Al-Mawaleh; (D) Al-Sahwa Public Park, Designated for Emergency Response [8]



Targeted evaluation methodologies have been developed for specific infrastructure types. [10] present a methodology for assessing the seismic structural vulnerability of wastewater treatment plants using Rapid Visual Screening, identifying 21 factors that determine vulnerability across general characteristics, seismicity and geotechnical data, technical data, and physical properties. Their analysis shows that seismicity and geologic data should be classified as critical vulnerability variables, including seismic hazard zones, damage from past earthquakes, ground category, foundation geometry, and past geotechnical failures. For example, when assessing foundation geometry, engineers inspect the layout and depth of foundations on site to determine susceptibility to differential settlement during an earthquake. To evaluate past geotechnical failures, records of soil instability or foundation issues in the plant area are reviewed to inform the overall vulnerability rating. These practical measures bridge the difference between theoretical assessment and applied practice.

[11] adapt FEMA P-1000 guidelines for Ecuadorian schools by incorporating characteristics of nearby geological faults, structural and nonstructural vulnerability levels, and construction system pathologies to produce a detailed seismic risk categorization. Their global seismic risk formulation relates total vulnerability and exposure levels to the capacity coefficient, which

reflects the facility's overall response capacity. The capacity coefficient quantifies a structure's ability to withstand seismic loads and is typically derived from its structural system and materials. A higher capacity coefficient indicates that a facility can withstand greater seismic forces before sustaining significant damage. Advanced observation technologies enhance conventional assessment methods (Figure 4).

Figure 4. Structural Failure of an Educational Facility Induced by the April 2016 Seismic Event [6]



[12] describe an interdisciplinary earthquake warning and rapid response system integrated with structural health monitoring, which detects structural damage in real time using interconnected, decentralized sensors. Sensor data collected from critical points within the infrastructure are transmitted to a central monitoring platform, where they are processed and converted into a compatible digital format. This information is imported into Building Information Modeling (BIM) models, where specific building elements are linked to live sensor readings through predefined data integration standards. Visualization tools within the BIM environment enable users to overlay sensor data onto the facility's digital representation, emphasizing regions of detected damage or abnormal structural behavior. As noted by [12], "The visualization of sensor data and the graphic representation of the detected damage provide spatial content to sensor data and serve as a useful and effective tool for the decision-making activities after an earthquake." This approach helps mitigate seismic risk, particularly for critical infrastructure in areas where, despite moderate seismicity, population and infrastructure density are high.

Vulnerability of Community Infrastructure Systems

Buildings and the Built Environment

The building stock represents the most visible and extensively studied component of community infrastructure vulnerability. Aging infrastructure significantly amplifies seismic risk; Montreal, for instance, ranks second in Canada for seismic risk, partly due to its "large population, aging infrastructure, and regional seismic hazards" [1]. In the European context, earthquake risk is highest in the Mediterranean and Balkan regions "due to the high seismic hazard, aging infrastructure, and concentration of populations and assets in high-hazard areas" [13].

The problem of pre-code construction is pervasive globally. In Palestine, “seismic-proof construction is rarely observed, and building codes in design and practices are not enforced,” with vulnerability indicators predicting total damage of 5–15% and partial damage of 20% in some urban areas [14]. Similarly, multifamily buildings in European urban areas face dual risks: “structural deficiencies caused by the buildings’ old age increase seismic risk, and the density of urban areas and other factors such as lack of green public spaces increase the risk of extreme heat.” The Lorca earthquake of 2011, despite its moderate magnitude, caused casualties and substantial structural damage, and an analysis of 406 reinforced concrete buildings revealed patterns of vulnerability linked to construction periods and applicable seismic code levels [14].

Preventive action requires systematic measures on buildings constructed before seismic classification to “strengthen their structure and prevent them from collapsing in the event of an earthquake.” The Christchurch earthquakes prompted a global review of building codes, emphasizing “the criticality of incorporating flexible materials, base isolation systems, and effective emergency response plans” and making seismic retrofitting of existing structures a focal point [15].

Lifeline Infrastructure Systems

Lifeline infrastructure—including water, power, transportation, and communication systems—is particularly critical because damage cascades through interdependent networks. Civil infrastructure systems “function as the arteries of modern urban communities” and are “becoming more integrated and interdependent through exchange of resources and exchange of information” [16].

In water systems, earthquakes can cause serious damage, disrupting the flow of safe water to customers and hindering activities essential to emergency response. Most water systems were built before current seismic design standards, meaning utilities must determine how to cost-effectively retrofit infrastructure to meet seismic requirements [17]. Earthquake damage to wastewater treatment plants may trigger cascading hazards, including liquefaction, landslides, tsunamis, and fires, with effects that persist for years and pose risks to health and public safety [10].

On the other hand, in electric power systems, [15] present frameworks for measuring the seismic strength of electric power supply systems and the communities they serve, using fragility functions to assess damage to system components. Their work reveals that “the strength of different community sectors can be enhanced by different power dispatch strategies” and that communities could enforce post-earthquake recovery performance objectives by intervening to change recovery priorities of critical infrastructure operators. [18] further point out the need for decision-support systems to assess the seismic risk of electric power networks, noting that despite significant research efforts, no user-friendly tool has been developed for asset managers and civil protection departments.

Likewise, in transportation systems, transportation infrastructure vulnerability directly affects evacuation capacity and emergency response. Damage to roads and highways, as evidenced by events such as the 1999 Chi-Chi and 2008 Wenchuan earthquakes, “could obstruct evacuation efforts, rendering people vulnerable to the seismic aftermath” [8]. The transportation system “sustains the economic and social well-being of the communities so that a disaster or extreme hazard, such as an earthquake, has a major impact on the strength of the communities” [7]. [19] demonstrate how the seismic vulnerability of key road infrastructure can reduce accessibility across metropolitan areas, with domino effects on access to medical facilities and emergency services.

Critical and Community Facilities

Schools, hospitals, shelters, and other community facilities require special attention. In Montreal, 67 earthquake shelters (mostly schools and community centers) were identified, and seismic screening methods were applied to assess their constructional and operational performance [1]. The collapse of a school at San Giuliano during the 2002 Italian earthquake and damage to schools during the 2009 L'Aquila earthquake prompted the development of seismic risk analysis procedures for school buildings, most of which were "designed and constructed ignoring seismic regulations, possibly resulting in a high seismic risk" [6].

Hospital operations during and after earthquakes are critical. The post-seismic functionality of hospitals "is linked to the good performance of the structure and the functional and operational components in their functional environment and not in isolation" [19]. When medical infrastructure is damaged or overwhelmed, delays in accessing appropriate medical care can lead to secondary health consequences, including increased risk of venous thromboembolism and exacerbation of respiratory diseases [20].

Social Vulnerability and Community Dimensions

Seismic vulnerability surpasses physical infrastructure to encompass social dimensions. Risk studies have identified social vulnerability as having a significant impact, with the combination of social and physical vulnerabilities potentially producing synergistic effects; for example, major disease status and moderate physical disability increased the risk of earthquake-related death by a factor of 1.5–2.5 in the 1999 Taiwan earthquake [1]. [21] demonstrate that adverse earthquake effects relate to "interacting conditions, some conditional on geography, some due to the characteristics of the building stock, and some having to do with the social characteristics of populations."

Community knowledge and preparedness are essential yet often insufficient. There is frequently "not enough community awareness and understanding of the potential seismic risk, although it is indispensable for successful hazard control plans" [2]. Weak preparedness can lead to increasingly severe impacts, including "high death tolls, serious injuries, considerable infrastructure damage, and the emergence of diseases resulting from disasters" [22]. Communicating risk assessments is vital for fostering community awareness and requires collaboration among engineers, urban planners, emergency responders, and legislators [15].

Resilience Frameworks and Recovery

Community Resilience Planning

Community resilience, defined as the ability to prepare for anticipated hazards, accommodate changing conditions, and withstand and recover rapidly from disruptions, is closely linked to the performance of the built environment. Recent policy developments have shifted from a sole focus on life safety toward objectives centered on functional recovery. The reauthorization of the National Earthquake Hazards Reduction Program (NEHRP) accentuated the importance of "functional recovery of the built environment to support community resilience" [23]. Maintaining the functionality of buildings and lifeline infrastructure enables community

members to return to their homes and businesses more quickly [24]. For earthquake-prone communities, pre-disaster recovery plans that explicitly address reoccupancy and functional recovery of buildings and lifeline infrastructure systems are essential [25].

Integrated Infrastructure-Community Recovery Models

Recent modeling methods capably capture the interdependencies between infrastructure systems and communities during the recovery phase. [16] introduce agent-based models that represent the behavior of infrastructure operators as they restore functionality. Their findings show that “timely and well-planned intervention in the recovery process can be very effective in alleviating the post-earthquake lack of toughness resulting from the insufficient supply of civil infrastructure service to meet the community demands.” Furthermore, the interactions among different agents and the interdependence between infrastructure systems “profoundly shape the recovery path for this integrated system.”

It is essential that resilience quantification frameworks account for changes in community demand following disasters, rather than focusing solely on infrastructure supply capacity. Conventional frameworks often assume that community demand remains constant, “which is usually not true after natural disasters, particularly earthquakes” [16].

Risk Reduction and Mitigation Strategies

Structural and Engineering Interventions

Engineering solutions for reducing seismic vulnerability span from seismic isolation and base isolation systems to resilient materials and smart technologies. Geotechnical seismic isolation represents a novel technique for reducing the vulnerability of civil structures and infrastructure [26]. The integration of sensors and monitoring systems provides early warning capabilities and real-time data for disaster response [11], [15].

For existing infrastructure, retrofitting remains the primary intervention. Seismic safety standards must be incorporated as infrastructure is repaired or replaced. Specific mitigation measures include integrating seismic resiliency into maintenance of underground facilities, identifying seismically unsound structures for retrofits, and upgrading roadways, sewer, water, and other infrastructure to withstand seismic shaking [27].

Urban Planning and Land-Use Management

Resilient urban planning adopts a multi-hazard approach, recognizing that cities face a spectrum of risks. Risk-informed planning requires careful assessment of vulnerabilities to various hazards when designing and locating critical infrastructure, considering factors such as seismic activity, flooding, and climate change [15]. The correlation between multi-hazard areas and built-up density informs prioritization of mitigation measures [28].

[14] demonstrate how seismic microzonation and territorial management tools can guide urban regeneration following earthquakes, covering innovative areas such as “territorial planning

and land use, after detecting phenomena associated with topography, urban growth in undue environments risk, or the urban configuration of buildings in an earthquake."

Education and Capacity Building

The education of construction professionals is critical for realizing long-term reductions in vulnerability. Recent examinations of vocational students' understanding of seismic-resilient infrastructure planning reveal significant knowledge gaps, particularly in post-disaster assessment methods. [29] highlights the need for architects in seismic regions to understand the causes and effects of earthquakes on infrastructure, seismic hazard estimation, and the principles of seismic-resistant design. Effective cooperation between structural engineers, geotechnical specialists, and architects is key to developing resilient built environments.

National Background

The history of structural design regulations in Colombia begins in 1984 with the Colombian Seismic-Resistant Construction Code, issued through Decree-Law 1400 of 1984. This was the first attempt to standardize the design and construction of structures nationwide and remained in effect for 14 years. Subsequently, Congress of the Republic approved Law 400 of 1997, under which the Seismic-Resistant Construction Regulations NSR-98 (1998) were issued, replacing the 1984 Code. The updated NSR-10 Regulation, issued in 2010, is currently in force.

The structure under study is a building for normal occupancy, which, according to records, is currently in use. It has one (1) story and was initially designed with a concrete frame structural system. The existing structural design followed the guidelines of NSR-98. For the study of earthquake and wind load stresses, the theory of Professor Blas Lamberti, published in the journal of the Venezuelan College of Engineers, was used. Finally, for the footing design, the 1951 ACI standards were considered.

Therefore, since the current standard governing seismic-resistant design guidelines stipulates the minimum requirements for the design and construction of buildings to ensure they can withstand seismic forces and increase their resistance to the resulting effects, it is necessary to conduct an evaluation and, if necessary, an intervention on the existing building to change its use and guarantee compliance with the requirements stipulated in Chapter A.10 of NSR-10. To that end, we analyzed several local studies, as described below.

[30] conducted a project applying civil engineering principles to assess seismic vulnerability and diagnose structural pathologies in Villavicencio, Colombia. Their main objective was to evaluate the seismic vulnerability of structural elements. The sample consisted of a visual inspection. The calculations were descriptive, non-experimental, and cross-sectional. Among the main pathologies identified were cracks, spalling, and dampness.

In conclusion, based on the minimum requirements of the Colombian Seismic Resistance Code (NSR-10), the structure's behavior during an earthquake was analyzed using ETABS. The analysis concluded that the elements do not have the required resistance for this event. Furthermore, most columns were under excessive stress, with a maximum Seismic Equation Index (ISE) of 6.57, indicating a 100% failure rate. Although there was no structural collapse,

elements such as columns and beams exhibited very high failure rates per the NSR-10 evaluation criteria. It was recommended that a more comprehensive study of all buildings on campus be conducted in the future to identify each building's vulnerability and determine whether structural reinforcement is feasible.

The study revealed a method for using structural design to determine whether an existing structure can withstand another earthquake and to assess the condition of its structural elements.

Other similar studies, such as the one conducted by [31], prioritized a systematic analysis of the available literature to identify the most frequent pathological defects in this region of the country. The methodology, based on compiling, classifying, and identifying the factors contributing to the most prevalent pathologies, identified the main standards governing the materials, processes, and designs that constitute the structure, and evaluated the parameters that affect and cause the defects.

In conclusion, the main pathologies present in Villavicencio were identified as dampness, cracks, and detachments, which originate from inadequate construction processes and design flaws. Furthermore, the materials used are not suitable for the area or the designs evaluated in the region. It was recommended that construction materials be properly identified, that a professional in the field monitor construction, and that a design be developed that complies with current regulations, particularly seismic-resistant standards. This study revealed that many pathologists reach the same conclusions: it is essential to exercise special care in selecting construction materials, ensure that designs comply with current regulations, and properly monitor construction processes.

In the next study by [32], the main objective was to identify structural and non-structural damage in homes to determine which are habitable and which are at risk of collapse. The methodology employed was quantitative, temporal, and spatial. It analyzed how information was gathered on the post-earthquake situation and the structural damage to buildings.

The study concluded by classifying buildings according to the degree of structural damage they exhibit, using a classification matrix defined for this purpose. This facilitated the identification of pathologies and their severity. A more comprehensive study on the classification of structural damage in the city of Bucaramanga is recommended; furthermore, the relevant entities must update the documentation required for this study. This study showed the importance of classifying the pathologies a structure presents after an earthquake, since a lack of knowledge of the actual damage can lead to catastrophic consequences. Special attention is required because these damages affect not only structures but also human lives.

MATERIALS AND METHODS

The qualitative analysis process, which began with a visual inspection, aims to identify and characterize the defects in the building and accurately locate them on the architectural plans. Each detected defect will be recorded with detailed photographic documentation and a de-

scriptive technical data sheet specifying the precise location, dimensions, defect type, and other relevant observations. Subsequently, all the information collected will be digitized and incorporated into the architectural plans using specialized computer-aided design (CAD) software, with a unique identifier assigned to each defect. This procedure ensures traceability, transparency, and reproducibility—fundamental elements in academic and scientific contexts.

Independent variable: operational parameters that lead to the development of structural pathologies because of deficiencies in the reinforcement systems. These parameters include the absence or inadequacy of structural elements such as beams or columns, improper use of materials, defects in construction joints, and corrosion of metallic elements. These factors will be identified and quantified through systematic visual inspections and recorded in descriptive technical reports that document indicators such as cracks in reinforced areas, noticeable deformations, structural discontinuities, and other relevant anomalies observed in the building.

Dependent variable: prevention of structural pathologies. This variable will be assessed by identifying and categorizing the strategies implemented or proposed to prevent the onset and progression of structural pathologies. The effectiveness of preventive measures will be verified by monitoring indicators such as the absence of new damage in the areas where work was performed, the stabilization or improvement of existing structural pathologies following the implementation of reinforcements, and strict compliance with the established technical criteria for mitigating structural risk. These indicators will be documented in descriptive reports and through periodic visual and photographic monitoring, enabling an objective and systematic evaluation within an academic context (Table 1).

Table 1. Variables Considered in the Study

Variable	Conceptual definition	Operational definition	Dimensions	Indicators
Cracks and fissures	Gaps that appear in the structure due to movement	Measured with crack gauges	A weekly inspection will determine whether the fissure or crack is active.	According to ACI 318, the parameters of fissures and cracks will be evaluated.
Structural reinforcement	The structure's capacity to withstand various external forces	Measured using a Ferrosan test	A scan of the structural elements will be performed to identify the type of reinforcement present.	It is evaluated using the parameters of the NSR-10 seismic resistance standard for structural steel, based on the conditions applicable to the structure under analysis.
Concrete strength	The capability of structural elements to withstand loads	Measured through a sclerometer test	A sclerometer test will be performed on several structural elements to verify the concrete's strength.	<i>Idem</i>

Variable	Conceptual definition	Operational definition	Dimensions	Indicators
Soil classification	Based on the foundation soil	Determined by conducting a geotechnical study of the site	Two boreholes will be drilled to a depth of 6 m for educational purposes, as the property is a historic landmark.	<i>Idem</i>
Allowable soil bearing	Soil's capacity to support loads	Calculated using the geotechnical study in which the building is located	<i>Idem</i>	<i>Idem</i>

The Women's Center exhibits structural pathologies that must be evaluated before reinforcing and adding two stories. The low compressive strength of the existing concrete in the Women's Center in Cota does not, in itself, preclude structural reinforcement for the two-story expansion. Still, it substantially increases intervention costs because it requires complex reinforcement or jacketing systems, limiting economic viability.

This study aimed to determine the pathological parameters that limit the feasibility of structural reinforcement for the Women's Center. To this end, the study must identify and classify the pathological cracking lesions in the structure according to their origin (design deficiencies, construction errors, or material quality issues). It is also essential to analyze the concrete's mechanical and physical properties using destructive and non-destructive testing to diagnose the internal causes of the structural degradation. Finally, assess the building's current seismic vulnerability to technically determine the feasibility or physical limitations of any potential structural reinforcement.

Technical Instruments and Methods Used

Ferrosan (Non-Destructive Testing)

This digital electromagnetic method detects, locates, and measures the diameter of reinforcing steel bars within hardened concrete elements [33]. It works by applying low-frequency magnetic fields and measuring the disturbances induced in the embedded ferrous elements [34]. For example, during a site assessment for the Women's Center, engineers can move the Ferrosan scanner along the surface of columns and beams. The device displays an immediate graphical representation of the steel arrangement, allowing the team to verify rebar placement before any demolition or intervention and reducing the risk of damaging structural elements. It enables the creation of as-built structural drawings for the Women's Center. This avoids drilling or cutting the existing steel during the intervention phase and assesses whether the current reinforcement quantity is suitable for the load redistribution of the two additional floors.

Core Extraction (Destructive Testing)

Concrete core extraction consists of obtaining cylindrical specimens directly from the structure using hollow diamond-tipped drill bits [35]. During this process, follow safety measures such as wearing personal protective equipment, securing the work area to prevent falling

debris, and avoiding excessive cutting near critical load-bearing elements to reduce the risk of structural weakening or accidents. These samples are subjected to axial compression loads in the laboratory to determine the material's actual mechanical strength. This key test empirically confirms the presence of "lean concrete" in the building. It provides the numerical data for compressive strength (f'_c) needed to model in the calculation software and to justify the redesign of the reinforcement.

Soil Study (Geotechnical Exploration)

The geotechnical study includes subsoil exploration through direct soundings, such as the Standard Penetration Test (SPT), to extract samples and identify the soil's physical, mechanical, and hydric properties. This study determines the bearing capacity, expected settlements, and seismic profile classification of the terrain [36]. Geotechnical investigations have limitations: tests are conducted only at selected points, so results may not capture soil variability across the entire site, and natural conditions, such as groundwater levels or past soil disturbances, can introduce uncertainties. Adding two floors will significantly increase the load on the ground. The study determines whether the soil in that specific area can withstand the added weight or whether the existing foundation will fail due to settlement, which would require micropiles or underpinning, drastically increasing the project budget.

Site Characteristics

The entire area will be the sample for this research. The Women's Social Center is a single-story building, approximately 20.80 m deep by 10.00 m wide, with a constructed area of approximately 208 m². Its architectural layout supports community and social functions, integrating defined spaces for collective activities, training programs, psychosocial support, and administrative management. The spatial configuration includes a multipurpose room for meetings and community activities with broad participation; a production unit for work, demonstration, or training; an exhibition hall that serves as both a circulation and display area; and a classroom for workshops and academic activities. The building also includes a psychosocial support space, an ASODAMAS observatory, an administrative area, an ancillary room, and two sets of restrooms distributed according to functional requirements. The outdoor area features a greenhouse that complements the project's production and educational components. The integration of these spaces demonstrates the infrastructure's multifunctional nature, aligning with its objective of providing support, guidance, and development opportunities for the municipality's community.

The Women's Social Center in the municipality of Cota, Cundinamarca, is a social facility aimed at strengthening community capacities and promoting the comprehensive development of women. Its creation responds to a local policy of inclusion, gender equity, and socioeconomic advancement, as well as to national initiatives led by the Association of First Ladies of Colombia (ASODAMAS), in coordination with the municipal administration. The project was inaugurated on March 8, 2018, and was established as a community support center designed to promote economic autonomy, technical training, and psychosocial support for women in the municipality. This space was conceived as a central hub for entrepreneurship, training, and social development programs.

During the administrative transition processes, especially in 2020–2023, structural deficiencies in facility management were identified. This included deterioration of movable assets, a lack of updated user databases, insufficient population profiling, and incomplete records of training and production processes. These deficiencies prompted corrective actions to reorganize the center's operations and documentation. After the necessary physical and administrative adjustments, the Women's Social Center reopened on February 4, 2020, resuming its social support, vocational training, and community-strengthening services. Since then, the facility has expanded its educational and production activities to include technical training programs, entrepreneurship workshops, psychosocial support, and artisanal and agri-food production units.

According to institutional reports, the Women's Social Center has directly benefited more than 3,000 women and has also offered complementary services to men and families involved in training and production programs. These results reinforce its role as a strategic support for promoting the social and solidarity economy in the municipality. As part of its recent evolution, the organization has strengthened its entrepreneurship and sustainability initiatives by providing production tools, offering training in textile activities, implementing educational programs, and supporting self-sustaining initiatives. These actions consolidate the Women's Social Center as a space for community innovation and socioeconomic development, directly contributing to improving the quality of life and the exercise of social rights for women in Cota.

In short, the Women's Social Center is an essential component of the municipality's social infrastructure, whose historical development reflects the transition from a welfare model to an approach focused on empowerment, productivity, and institutional strengthening. Its management integrates administrative, training, and community components, making it a local benchmark in social policy focused on gender and sustainable territorial development.

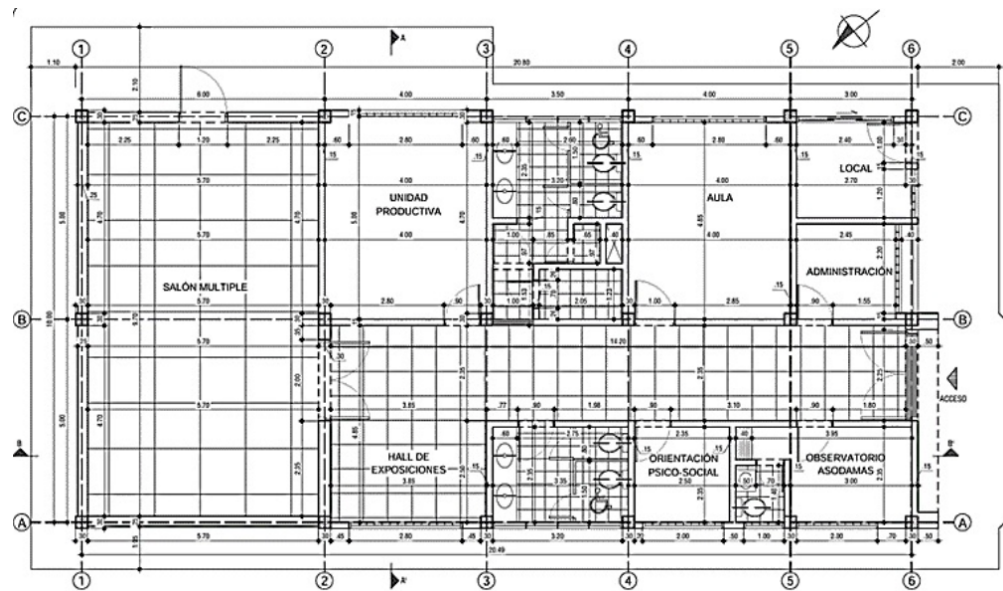
The facilities were surveyed to define the spaces and determine the observed pathological damage.

RESULTS

As a first step in the study, a pathology analysis was performed. Using the pathology data, a vulnerability assessment and a proposed reinforcement plan were developed. A methodology based on field observation was employed, enabling inspection and recognition of the structure under ambient conditions. The data collection phase enabled assessment of the building's current state of conservation and maintenance and identification of existing pathological processes within the structure, which were documented with photographs. The sampling phase also involved conducting both destructive and non-destructive material tests to evaluate the mechanical properties of the materials comprising the structural elements.

Using the information obtained, a preliminary evaluation was conducted to determine the causes of the pathological processes affecting functionality and structural behavior. Visual inspection identified pathological damage to the structure of the Women's Center. The building's layout is shown in Figure 5.

Figure 5. Existing Area Distribution Plan



The pathological lesions listed below were systematically identified during a comprehensive visual inspection of the structure. This methodical process used standardized diagnostic protocols to ensure consistency and reliability in detecting anomalies. Each lesion was meticulously documented, not only describing its physical characteristics and precise location within the building but also assessing its potential implications for the building's structural integrity. The findings are comprehensively presented in Table 2.

Table 2. Classification of Pathological Lesions

Type of damage		
Physical and mechanical	Chemical	Biological and anthropogenic
Crushing	Corrosion	Decomposition
Settlement or movement	Damage to exposed concrete and steel	Erosion and undermining
Shear block	Concrete damage/corrosion	Dampness
Shear	Welding discrepancies	Infiltration
Eccentricities	Missing rivets and/or bolts	Dirt
Cracks		Other aspects
Fissures		
Impact		

Type of damage		
Physical and mechanical	Chemical	Biological and anthropogenic
General buckling		
Tension		
Excessive vibration		

Seismic Vulnerability Study

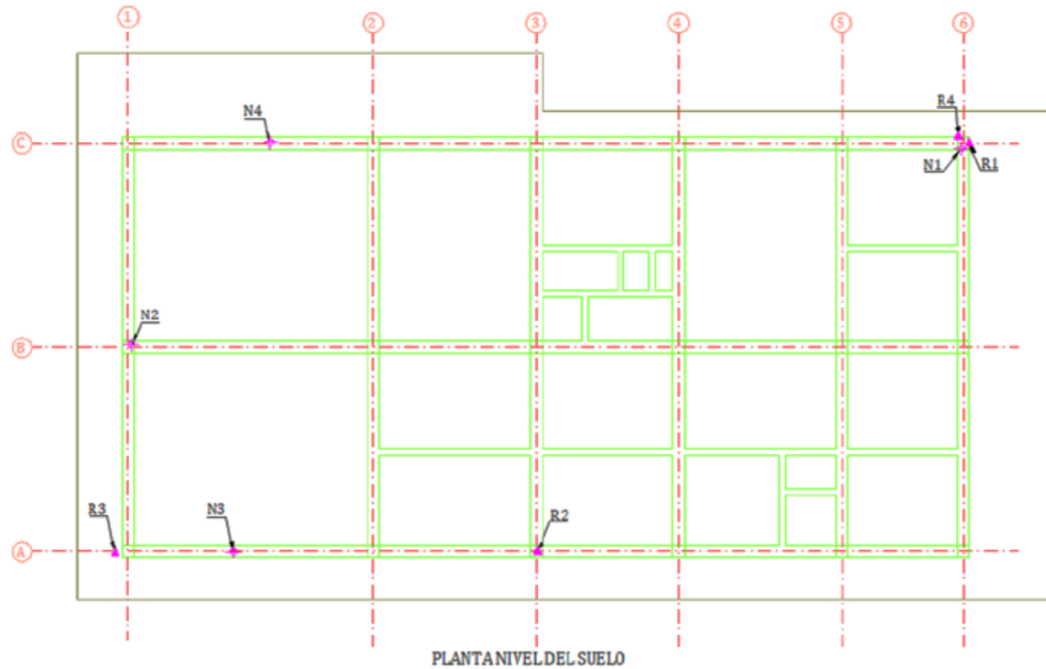
After identifying the structural damage, the destructive and non-destructive tests reported in the seismic vulnerability assessment were performed. A structural vulnerability report was prepared for a one-story building on Calle 3, between Carrera 5 and Carrera 2B, in the municipality of Cota, Cundinamarca, in accordance with the requirements of Chapter A.10 of the NSR-10. The building under study is slated for expansion with the addition of two floors for office use.

The structure under study is a building with normal occupancy, which, according to records, is currently in operation. It has one story and was initially designed with a concrete frame structural system. The existing structural design followed the guidelines of NSR-98. For the study of earthquake and wind load stresses, the theory of Professor Blas Lamberti, published in the journal of the Venezuelan College of Engineers, was used. Finally, for the footing design, the 1951 ACI standards were considered.

The current standard governing seismic-resistant design guidelines stipulates the minimum requirements for the design and construction of buildings to ensure they can withstand seismic forces. Therefore, it is necessary to conduct an evaluation and, if necessary, an intervention on the existing building to change its use and guarantee compliance with the requirements stipulated in Chapter A.10 of NSR-10.

During the visual inspection, the structure appeared to be in good condition. No significant pathologies were found, aside from some cracks in non-structural elements, which are presumed to be due to seismic activity over the building's lifespan. Additionally, we performed various tests to determine the condition of the existing structure; these tests are shown in Figure 6.

Figure 6. Location Plan of the Extracted Core Samples and the Field Tests Carried Out in the Existing Area Distribution Plan

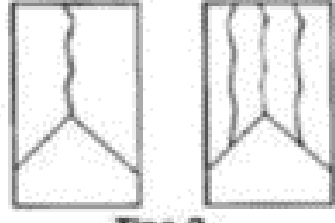


The cores were extracted perpendicular to a horizontal surface, ensuring their axes were perpendicular to the concrete layer as originally placed, and avoiding any obvious joints or edges of the structure. Specimens taken perpendicular to a vertical or irregular surface should be extracted as close as possible to the center of the element and never near joints or edges. The cores were extracted from a volume 4.2 cm in diameter and 8.5 cm in length. Four (4) core extractions were performed.

In NSR-10, Chapter C states: "For structural concrete, f'_c should not be less than 17 MPa (2465 PSI). No maximum value for f'_c is established, nor does any specific provision of Title C restrict it." Furthermore, section C.5.6.5.4 states that the concrete in the area represented by the cores is considered structurally adequate if the average of three cores is at least 85 percent of f'_c , and no single core has a strength less than 75 percent of f'_c . When core values are erratic, additional cores may be extracted from the same area.

Based on the above and the core results, the structure does not meet the minimum concrete strength required by NSR-10, as the average strength of the tested elements is 10.6 MPa. Table 3 presents the results obtained from testing the concrete core samples in accordance with the previously referenced technical standard. This comprehensive tabulation provides quantitative data essential for the rigorous evaluation of material performance and structural integrity against established engineering criteria.

Table 3. Results of Concrete Core Tests Performed at the Analysis Site

Element in the structure	Strength (PSI)	Strength (MPa)	Failure type
Column - main entrance	1464.0	10.64	
Center column - rear	1423.0	10.21	
Upper left beam - green-house	1467.0	10.52	
Beam on the right side - upper part	1526.0	10.94	

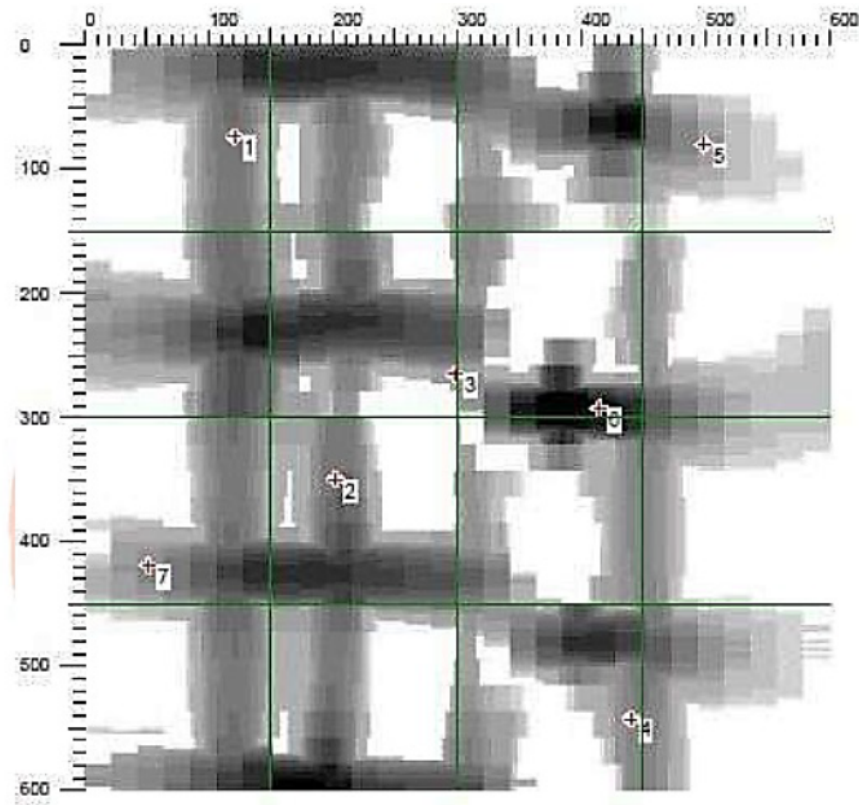
To thoroughly assess the integrity and durability of the structural reinforcement within the seismic resistance system, a series of exploratory test pits were meticulously excavated at strategically determined locations. This investigative procedure, carried out in accordance with rigorous engineering standards and best practices, facilitated direct access to the embedded reinforcing steel, thereby enabling comprehensive visual and tactile examinations. The inspection process involved detailed documentation of the physical condition, cross-sectional area, and surface characteristics of the steel bars, with particular attention to any signs of corrosion, pitting, or other forms of deterioration that could compromise structural performance. The results of these evaluations were unequivocal: no traces of corrosion or material degradation were detected in any of the surveyed reinforcement elements. This finding, as shown in Figure 7, attests to the effectiveness of the construction techniques employed and the adequacy of the environmental protection measures, reinforcing confidence in the building's long-term structural reliability and safety.

Figure 7. a) Corner, b) Pitting, and c) Pitting Without Corrosion



The results presented herein correspond to the various locations within the structural framework where the Ferroskan non-destructive testing methodology was systematically applied to identify, map, and characterize the embedded reinforcing steel elements (see Figure 8).

Figure 8. Example of a Ferroskan Test Carried Out on the Structure Under Study



This advanced diagnostic technique, grounded in the principles of electromagnetic induction, enabled precise detection of rebar positions, estimation of bar diameters, and assessment of concrete cover thickness across multiple critical sections of the structure (Table 4). The comprehensive data generated from these test points provide valuable insights into the spatial distribution, continuity, and conformity of the reinforcement system relative to the original design specifications. Such detailed analysis serves not only as a basis for evaluating compliance with engineering standards but also informs potential recommendations for maintenance, retrofitting, or further structural investigation, as required, to ensure the building's ongoing safety and performance.

Table 4. Results of Concrete Core Tests Performed at the Analysis Site

Ferroscan	Location	Vertical reinforcement			Horizontal reinforcement		
		Diameter	Depth (mm)	Gap (mm)	Diameter	Depth (mm)	Gap (mm)
1	Floor 1 Axis C-3 Column 1	3/4"	60	80–150–120	3/8"	48	80–150
2	Floor 1 Axis C-3 Column 2	3/4"	67	80–150–120	3/8"	67	350–150
3	Floor 1 Axis A-2 Column 3	3/4"	54	80–150–120	3/8"	36	200–300
4	Floor 1 Axis A-2 Column 4	3/4"	59	80–150–120	3/8"	41	150
5	Floor 1 Axis C between 3 and 4 Beam 1	Reinforcements not determined by their depth					
6	Floor 1 Axis C between 3 and 4 Beam 2						
7	Floor 1 Axis C between 3 and 4 Beam 3						
8	Floor 1 Axis C between 3 and 4 Beam 4						
9	Floor 1 Axis B-4 Column 5	3/4"	42	100	3/8"	84	125
10	Floor 1 Axis B-4 Column 6	3/4"	31	Not applicable	3/8"	67	150–200

State of the Structural System

The evaluation of the current structural system is entirely qualitative and considers the quality of the original structure's design and construction relative to its current state. The NSR-10, in section A.10.4.3.4 Effective Resistance, establishes resistance reduction coefficients, which will be explained later in the section on the resistance of the elements in the existing structure. However, Table A.10.4-1 provides parameters for assessing the quality of the building's design and construction.

Based on the overall findings, several key observations are warranted regarding the design and construction quality of the evaluated structure. The assessment assigns a rating of GOOD ($\Phi_c = 1.00$) to the design and construction quality, predicated upon the existence of an applicable design code at the time of construction, the structure's adherence to consistent dimensional standards, the incorporation of a seismic resistance system, and the use of a

systematic construction methodology. These factors collectively reflect a robust and deliberate approach to the building's original design and construction.

Nevertheless, the evaluation of construction condition quality yields a rating of FAIR ($\Phi_e = 0.80$). This classification indicates that, while the structure remains in active service, it fails to meet the minimum concrete compressive strength requirements for this typology, specifically, a specified strength (f'_c) of 17 MPa (2,465 psi). This shortfall in material performance underscores the need for continued monitoring and potential remedial action to ensure the facility's ongoing safety and reliability.

Structural System Classification

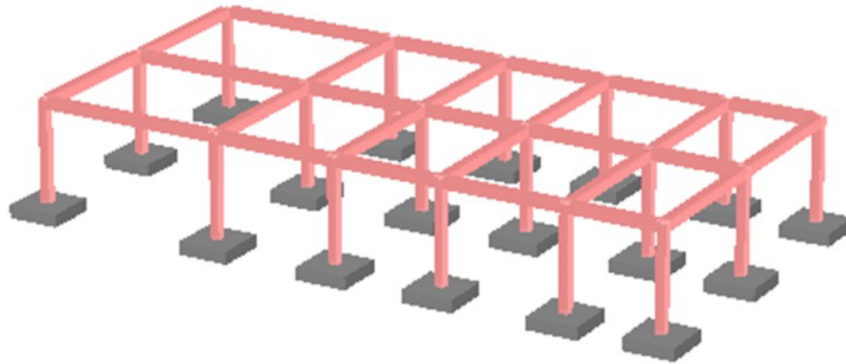
According to Chapter A.3, the structural system is a Moment-Resisting Frame (MRF) system that resists all vertical loads and horizontal forces. Therefore, a value for the energy dissipation capacity coefficient, R' ($R = \Phi_a \cdot \Phi_p \cdot \Phi_r \cdot R_o$), is assigned (A.10.4.2.4). For the case under analysis, and considering that the structure is an MRF located in an intermediate seismic hazard zone, an R' of 5.0 will be assumed, equivalent to a structure under the same conditions, as indicated in Table A.3-3 of the NSR-10.

The design analysis method used was dynamic analysis, employing a three-dimensional model with a rigid diaphragm that spatially distributes the structure's mass and stiffness. The load assessment was defined using seismic-resistant building codes and the existing structural conditions. We defined 0.015 t/m² for the architectural tile roof, 0.010 t/m² for the ceiling, and 0.050 t/m² for the live load. Additional distributed loads from the roof's gable ends were entered directly into the software for the supporting beams.

As indicated in NSR-10 section A.10.4.3.4, the effective strength (N_{ef}) of the elements or of the overall structure must be evaluated as the product of the existing strength (N_{ex}) multiplied by the strength reduction coefficients (Φ_c) and (Φ_e).

In this way, the strength below which the elements' overstress indices will be evaluated is determined. Considering the existing design information, the adopted design parameters, and the fact that the structure has been subjected over the years to seismic events that, although not of great magnitude, have not significantly affected its behavior, it is concluded that the design quality is good. However, according to the laboratory results, the concrete strength, as mentioned previously, does not comply with the provisions of NSR-10; therefore, the quality of the building's construction is fair. Figure 9 presents the models used in the design software to determine the structure's vulnerability. This software was used to verify the structure's vulnerability under current conditions.

Figure 9. 3D Model View



Structural Analysis

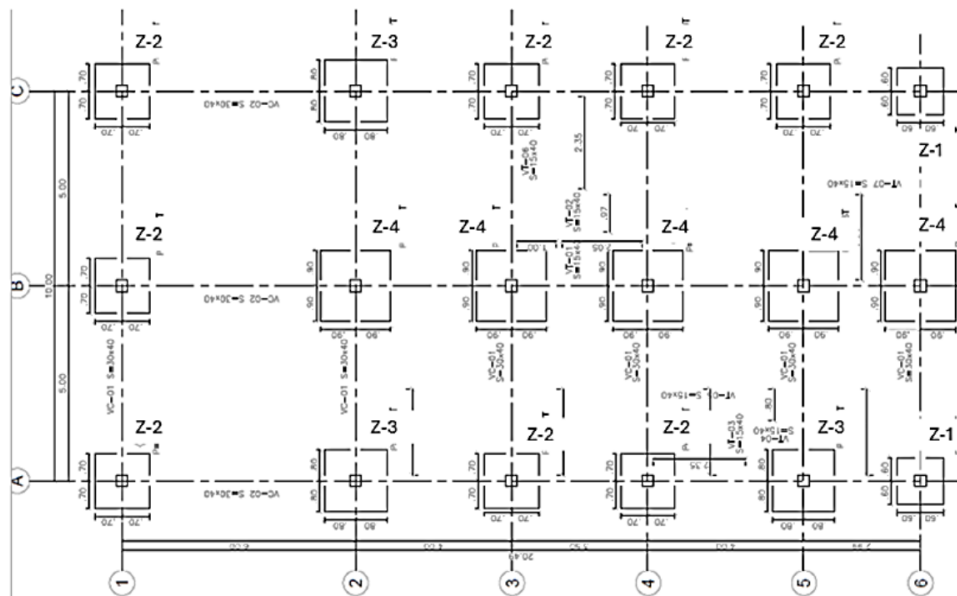
The design actions under the loads given in the previous chapters were determined using a spatial mathematical model with six degrees of freedom per node, solved with EngSolutions RCB, version 9.0.9. The structure is idealized as an assembly of columns, beams, diagonals, and walls, interconnected by floor diaphragms that are either rigid or elastic in their own plane. The structure's basic geometry is defined with reference to a three-dimensional mesh formed by the intersection of floor levels and vertical column axes. The column axes are defined by an architectural axis system consisting of longitudinal and transverse axes for rectangular buildings and radial and circumferential axes for cylindrical buildings. The program allows modeling partial diaphragms, such as mezzanines and openings. It can also model multiple diaphragms at each level, enabling analysis of buildings composed of several towers derived from a common platform at the lower levels. The analysis automatically incorporates the effects of finite beam and column dimensions on the structure's stiffness. The design analysis method used was dynamic analysis, employing a three-dimensional model with a rigid diaphragm that provides a spatial distribution of the entire structure's mass and stiffness.

After running the program, the numerical modeling results complied with the 1.00% drift limit, as specified in Chapter A.6 of the NSR-10. The stress indices were calculated using EngSolutions RCB software, which was used for structural modeling and analysis. The existing material properties were assigned, and the stresses acting on the elements were calculated. Subsequently, the stress indices for the columns were reviewed using CSICol software, accounting for additional strength reduction factors associated with design quality and the structure's condition, as shown below. For the beams, the existing resistance to the applied loads and stresses was verified directly.

The stress limits for the columns and beams were calculated, revealing acceptable values for the structure. Since the reinforcing steel could not be identified, a minimum reinforcement ratio equivalent to three #4 bars (3.87 cm^2) was assumed.

According to the soil study, the bearing capacity in the study area at the existing foundation depth (1.80 m) is 14.9 t/m^2 . Based on this and the modeling results, the stress index analysis was performed considering the foundation locations, as shown in Figure 10. As evidenced, the stress indices of the existing foundation are less than one; therefore, it is not considered vulnerable, and intervention is not necessary under the current conditions.

Figure 10. Location of Foundation Footings



Regarding the drift measurements, the flexibility index is below 1; therefore, the structure is not classified as vulnerable with respect to this parameter. We verified the beams' flexibility indices under the structure's current conditions. Based on the beam deflection calculations, these elements show no significant flexibility.

Analysis of Vulnerability Results

As a result of the findings, the concrete compressive strength (F'_c) was found to be less than 17 MPa, which is the minimum required by section C.1.1 of the NSR-10. The stress indices of the structural elements (columns, beams, and footings) do not exceed 1 in most cases; however, the concrete strength is inadequate for a potential two-story office expansion. This prevents the structure from performing adequately under the new service and seismic loads resulting from the change of use. Therefore, the structure is vulnerable, even though it does not currently exhibit severe damage.

The structure's flexibility index does not exceed the maximum allowed by the standard; however, if the expansion is carried out, the existing sections and the deficiencies in the material properties will not guarantee that the structure will remain within the established flexibility limits.

Considering these results, the following is recommended: due to the current state of the structure, the low compressive strength of the concrete, and the proposed expansion with two additional office levels, structural reinforcement capable of withstanding each and every one of the loads and requirements of the NSR-10 is suggested as the most viable alternative.

Reinforcement Analysis

The analysis and vulnerability study concluded that the concrete in the existing frames does not meet the requirements established in Title C of the NSR-10 and therefore does not guarantee adequate performance under the service and seismic loads required by the code. Therefore, the structure's strategic underpinning is considered necessary.

After conducting the necessary studies and designs in compliance with the country's current construction and seismic-resistance standards, a reinforced-concrete frame system is proposed. This system will strategically reinforce certain column and beam axes on the first floor to ensure adequate performance under the new loads.

In accordance with the seismic requirements of NSR-10, these frames will be designed to develop a moderate energy dissipation capacity (DMO). They will be integrated into the existing foundation, a shallow system consisting of footings and connecting foundation beams.

The structure was reinforced according to the following parameters for each structural element, as shown in Table 5.

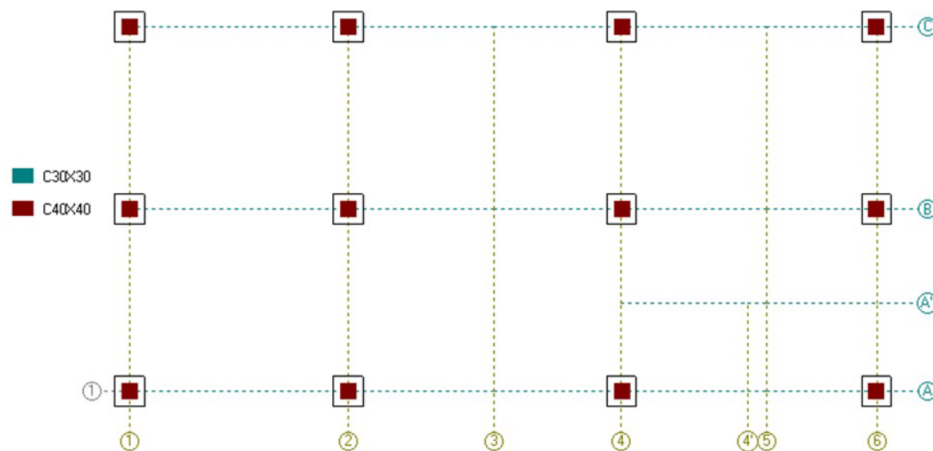
Table 5. Description of the New Project

Project description	
Floor numbers	3
Floor height	3.25 m
Column section	0.40 m x 0.40 m
Beam section	0.40 m x 0.45 m
Foundation depth	1.80 m
Foundation type	Shallow (continuous or isolated footing)
Contact pressure	14.90 t/m ²
Soil type (NSR-10)	E
Roof type	Lightweight

Note. Adjusted according to the entity's request for a two-floor expansion for office use.

Figure 11 shows the proposed reinforcement structure, in which the number of vertical frames is reduced from six to four while maintaining the original structure. As previously indicated, the three horizontal beams underwent jacketing of the structural elements, meaning the existing section was enlarged with higher-strength concrete to meet the limits permitted by NSR-10. As shown, the frames on axes 3 and 5 were discarded because the structure is redundant and they are unnecessary.

Figure 11. Plan View of the Base of the Reinforced Structure



Conclusions

Overall Visual and Reinforcement Condition: The building appears to be in good physical condition, with no significant structural defects, aside from minor, non-structural cracks. Furthermore, exploratory test pits and Ferrosan scanning confirmed that the embedded steel reinforcement is well-preserved, showing no signs of corrosion or material degradation.

Foundation and Soil Adequacy: The existing shallow foundation system is adequate under the building's current configuration. Geotechnical testing determined a soil bearing capacity of 14.9 t/m² at a depth of 1.80 m, and structural modeling showed that the foundation's stress indices remain below 1.0, indicating it is not presently vulnerable.

Critical Deficit in Concrete Strength: The most significant structural flaw lies in the quality of the materials used. Core extraction tests revealed an average f'_c of 10.6 MPa. This falls well below the 17 MPa minimum required by the NSR-10.

Feasibility of Vertical Expansion: Due to substandard concrete strength, the current structure is considered vulnerable and cannot safely support the new service and seismic loads that a two-story vertical expansion would impose. While the building's current flexibility and drift are within permitted limits, adding two additional office levels without intervention would prevent the structure from meeting NSR-10 requirements.

Required Structural Intervention: For the two-story expansion to be viable, strategic structural underpinning and reinforcement are necessary. The proposed engineering solution involves "jacketing" existing elements—enlarging the cross-sections of specific columns and beams using higher-strength concrete—and modifying the frame layout by reducing the number of vertical frames from six to four to safely accommodate the new loads.

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