Structural modeling of steel profiles to infer preventive maintenance in educational infrastructure

Modelado estructural de perfiles de acero para inferir mantenimiento preventivo en infraestructura educativa

Gutiérrez-Can, Yuriko*[a], Palemón-Arcos, Leonardo[b], Naal-Pech, José Wilber[c] and Álvarez-Arellano, Juan Antonio[d]

[a] Universidad Autónoma del Carmen • KHW-2340-2024 • 0000-0001-6358-2130 • 798108
[b] Universidad Autónoma del Carmen • KHW-2160-2024 • 0000-0001-9743-0434 • 49334
[c] Universidad Autónoma del Carmen • KHW-2538-2024 • 0009-0006-2955-0382 • 1231951
[d] Universidad Autónoma del Carmen • JRX-8666-2023 • 0000-0001-6341-417X • 273636

CONAHCYT classification:

DOI: https://doi.org/10.35429/H.2024.13.56.66

Area: Engineering
Field: Engineering
Discipline Mechanical Engineering
Subdiscipline: Planning

Key Handbooks

The contribution will be in two aspects: engineering and academic. The first will contribute to show the engineering rehabilitation of the entire structure deteriorated by corrosion. In the academic environment, it will contribute to the methodology to infer the behaviour or performance based on the current regulations governing this type of structure. The methodology for the rehabilitation of the entire structure deteriorated by corrosion of all the profiles. According to the current condition with deterioration, the structure does not comply with the two limit states, understanding that a limit state of behaviour is reached in a construction when a combination of forces, displacements, fatigue levels, or several of them, that determines the beginning or the occurrence of an unacceptable behaviour mode of said construction.

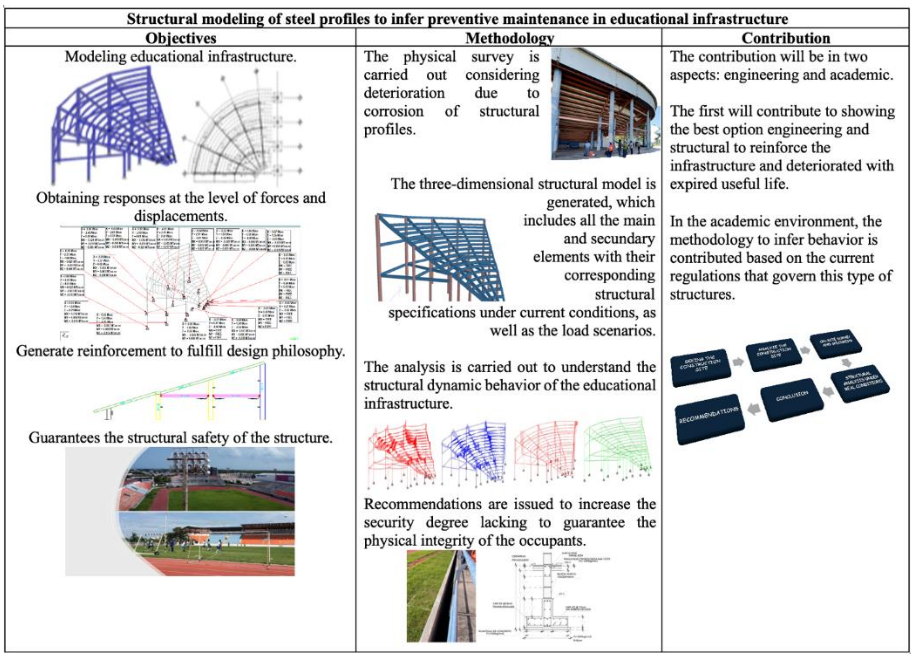
Citation: Gutiérrez-Can, Yuriko, Palemón-Arcos, Leonardo, Naal-Pech, José Wilber and Álvarez-Arellano, Juan Antonio. 2024. Structural modeling of steel profiles to infer preventive maintenance in educational infrastructure. 56-66. ECORFAN.

* ✉ [doc-034@itsperote.edu.mx]

Handbook shelf URL: https://www.ecorfan.org/handbooks.php

Abstract

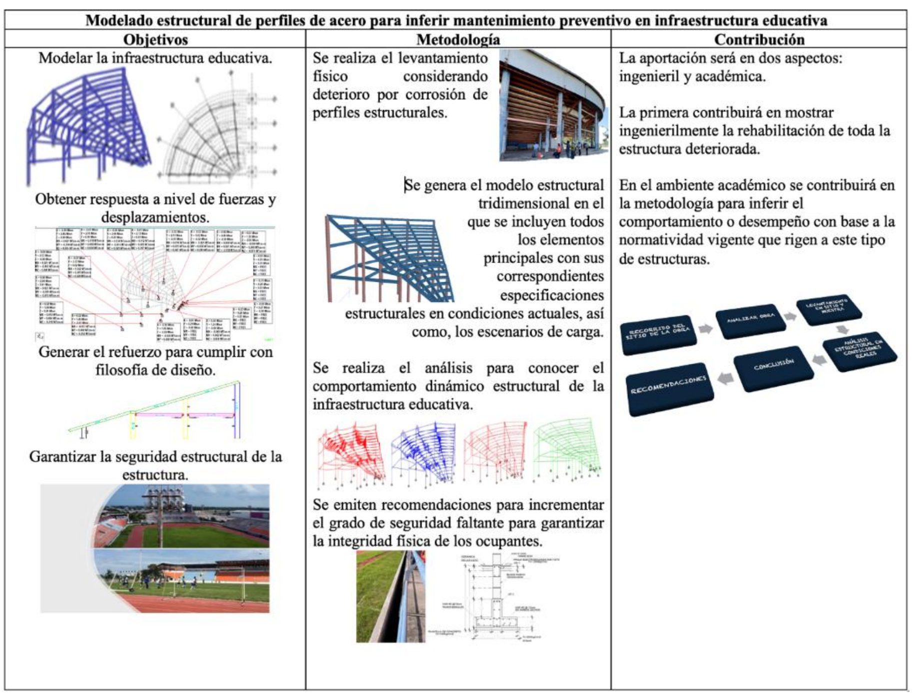
The useful life of an infrastructure depends on the preventive maintenance provided during its use, however, abandonment due to various situations accelerates the deterioration of the elements that comprise it, so it is necessary to rehabilitate them by carrying out mandatory modeling and simulation in the real conditions in which the structure is located. Therefore, this work shows the modeling under real corrosion conditions of structural profiles that make up the support system of the steps of a stadium. It is determined that all the structural elements that make up the educational infrastructure require reinforcements due to the reduction in thickness due to corrosion, this is because the portable capacity of the stadium is reduced.



Structural steel, Maintenance, Rehabilitation

Resumen

La vida útil de una infraestructura depende del mantenimiento preventivo que se brinde durante su uso, sin embargo, el abandono por diversas situaciones acelera el deterioro de los elementos que lo conforman, por lo que es necesario rehabilitarlas realizando obligatoriamente una modelación y simulación en las condiciones reales en la que se encuentra la estructura. Por tanto, el presente trabajo, muestra el modelado bajo condiciones reales de corrosión de perfiles estructurales que integran al sistema de soporte de las gradas de un estadio. Se determina que todos los elementos estructurales que integran la infraestructura educativa requieren refuerzos por la reducción de espesor por corrosión, esto debido a que se reduce la capacidad portante del estadio.



Acero estructural, Mantenimiento, Rehabilitación

Introduction

Human beings are constantly looking for comfort, protecting themselves from the harmful conditions generated by nature, and that with engineering this comfort is provided by taking care of the physical integrity of the structure with a reasonable safety factor ranging from 1.5 to 3.0 ensuring that the probability of structural failure is low (Van *et al*., 2024). In addition, working together with other specialties confirms that the structure is safe, functional, economical and without visual contamination with the trajectory and intervention of professionals according to the phases of the work, as shown in **Figure 1.**

Box 1

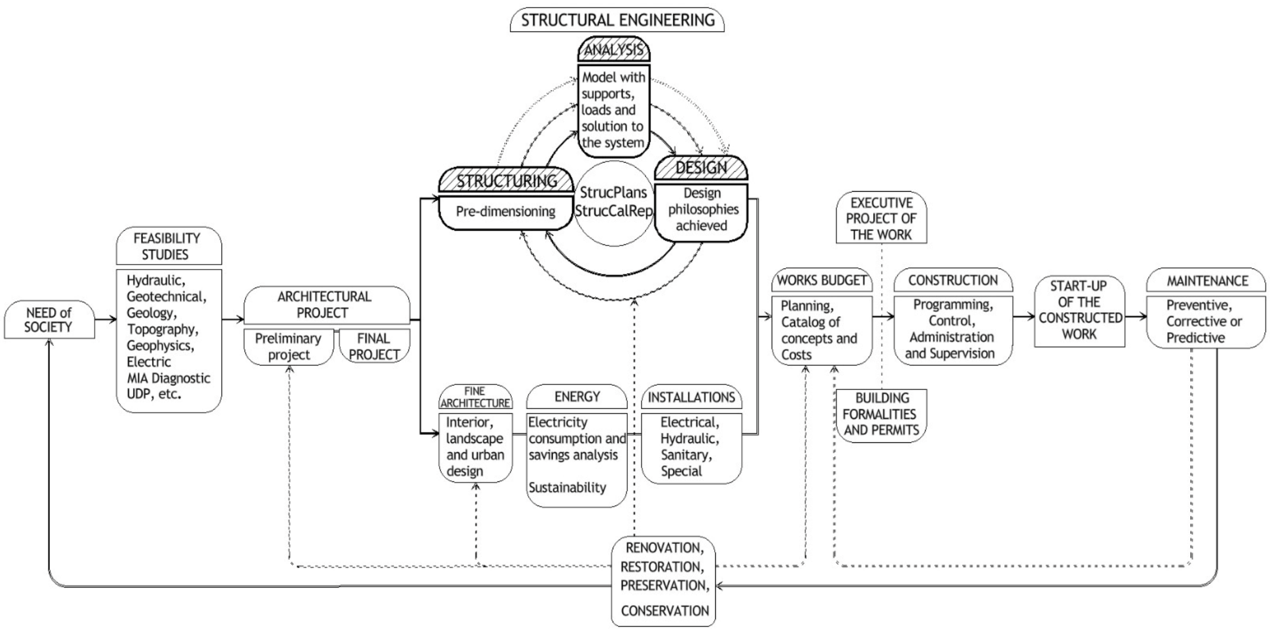


Figure 1
Trajectory of any project

It should be noted that every project is triggered by a need to provide a service to society, carrying out prior studies to assess feasibility. In addition, it is noted that at the end of construction, maintenance is required, where preventive maintenance aims to maintain the normal operation of equipment and assets, avoiding costly downtime due to unexpected failures (Sun *et al.*, 2022).

It is also noted in **Figure 1** that the project cycle includes refurbishment, so it is important to emphasise that refurbishment is an essential part of system resilience, and it is natural to adopt resilience measures in maintenance planning throughout the educational building where financial, human, material and time resources are very limited. In addition, resilience comprises three main capacities: absorption, adaptation and restoration (Sun *et al.*, 2022), however, to maintain the initial load capacity must be rehabilitated by placing reinforcements based on the results obtained, this because the infrastructure is located in Ciudad del Carmen Campeche, which is an island bordering the Gulf of Mexico (Fuentes *et al*., 2018), so engineers who build, design and provide maintenance to the infrastructure in this area, we must consider the local conditions that prevail in the environment, which is an aggressive environment. That is to say, in this area the corrosion of steel elements is imminent, due to the high concentration of salts in the environment. For this reason, although at a global level steel is an ideal element to accelerate the construction process, the materials degrade gradually and constantly if it does not have the initial corrosive protection during its useful life. In addition to the above, approximately 360 km away is the border where the interaction of two tectonic plates is present: cocos and North American, where seismic movements are generated and can cause weakened or degraded structures to collapse due to corrosion.

Therefore, this work shows the methodology applied to arrive at the necessary reinforcements by generating the modelling, simulation and analysis with specialised software. Furthermore, once the basic loads have been estimated, as well as the scenarios or combinations of them, the behaviour under real conditions is inferred in order to detect the weak profiles. Subsequently, a conclusion and recommendations are made to guarantee structural safety.

Methodology

Corrosion affects structural profiles including welded joints (Yelamasetti *et al*., 2024), especially when these profiles were subjected to high temperatures when welded and were not immediately protected or retouched by anti-corrosion processes, so that over time the element accumulates rust until the core, connections, or the fundamental parts of the structure are calcined. That is, having the elements outdoors, as well as exposed to the accumulation of water or runoff in areas of difficult intervention deteriorates and weakens structurally, however, at first glance you can not infer the decline of the structural capacity, so the following methodology should be used: visit the site in question of educational infrastructure, physical survey of the structure, collation of initial engineering, modelling and simulation in real conditions and finally issue recommendations to ensure the physical integrity of the work. As a fundamental part is the simulation, which Daou *et al*., (2019) indicates that simulation is one of the most applicable techniques used in cases where it is difficult to solve an equation analytically.

The phases of the project in question described in this section are described in detail. As a first step, a tour of the site is carried out to identify the needs of the project to be rehabilitated, verifying the degree of deterioration in corrosion in which the work is located. Subsequently, the dimensions or characteristics of the current state are taken, removing the paint and loose rust resulting from oxidation.

Next, the work is analysed by comparing the final plans with the existing ones, i.e. the specifications are studied with the data collected on site as a result of the initial execution of the project using as-build plans and, in general, the hidden defects on site, complementing the missing information. It is concluded from this stage that the plans do not coincide with what was built.

The structural model is elaborated considering joints, boundary conditions, basic loads and their combinations to infer the behaviour in the worst case scenarios.

In this work, three categories of loads will be considered according to the duration in which they act on the structures with their maximum intensity: permanent, variable and accidental.

Permanent actions are defined as those that act continuously on the structure and whose intensity varies little over time (NTC, 2023). The main actions that belong to this category are: dead load, static thrust of soils, liquids, deformations and displacements imposed on the structure that vary little over time, such as those due to prestressing or permanent differential movements of the supports. **Table 1** shows the loads of this item in which the weight of all the construction systems and finishes are considered, while the self-weight of the beams and columns will be generated within the specialised software through the ‘selfweight’ command.

Box 2

Table 1

Dead loads of education infrastructure

No.	Construction system	**Magnitude (kg/m^2)**
1	Galvadeck 25 gauge 22 with 6cm compression layer.	220
2	Finished floor finish	120
3	Installations, ducts and soffits	45
4	Regulatory additional weight	40
	Total	425 kg/m^2

Variable actions are those that act on the structure with an intensity that varies significantly with time (NTC, 2023). The main actions that fall into this category are: live load; temperature effects; imposed deformations and differential subsidence that have a time-varying intensity; and actions due to the operation of machinery and equipment, including dynamic effects that may occur due to vibration, impact or braking. **Table 2** shows the loads of this item in which three types are considered: maximum (Wm), instantaneous (Wa) and average (W).

Box 3

Table 2

Live loads of education infrastructure in kg/m^2

Destination of floor or roof	**W**	**Wa**	**Wm**
Stadiums and venues without individual seating	40	350	450

Source: *NTC, 2023*

The maximum live load **Wm** should be used for structural design for gravity forces and for calculation of immediate settlements in soils, as well as for structural design of foundations for gravity loads; the instantaneous load **Wa** should be used for design for accidental loads, such as earthquake or wind, and when checking load distributions more unfavourable than uniformly distributed over the whole area, and the mean load **W** should be used in the calculation of deferred settlements and for the calculation of deferred deflections.

Accidental actions are those which are not due to the normal operation of the building and which can reach significant intensities only for short periods of time. This category includes: seismic actions; wind effects; hail loads; effects of explosions, fires and other phenomena that may occur in extraordinary cases. It will be necessary to take precautions in the structures, in their foundations and in the construction details, to avoid catastrophic behaviour of the structure in the event of these actions occurring. In the case of the present work, the load generated by earthquakes (CFE, 2015) will be estimated using the prodisis using the site location described in the introduction section, while the wind load will be estimated using the wind system software (CFE, 2020) of the National Institute of Electricity and Clean Energy (ntc).

When the description of the behaviour of a structural system is required, the formulation of a mathematical model is used (Sarath *et al*., 2020). This formulation is done by means of equations that reflect the properties, geometry, materials and the interaction between the elements. Different sets of equations then appear that can be related to each other to achieve the final formulation. The model with basic loads and load scenarios, from which results of the behaviour of the structure under real conditions will be obtained, and recommendations will be issued to address the findings.

The physical and mechanical characteristics of the existing profiles in the project are shown in **Table 3**, in which the safety assessment and reliability analysis of a structure as a function of time depends mainly on the corrosion model, which directly affects the accuracy of the calculation (Wu *et al*., 2021). Destructive testing yielded an fy = 3,314.08 $^{kg/cm2}$ and E = 2,039.432 $^{kg/cm2}$, the magnitude of which was reliably generated (Kostic *et al*., 2022).

Box 4

Table 3

Specifying the profiles that make up the infrastructure

ID	**Structural profile**	**Specification**
C-1	OC-508 mm x 12.7 mm	A-500 Gr. B
C-2	OC-406 mm x 12.7 mm	A-500 Gr. B
TR-1	IR-356 mm x 50.7 kg/m	A-572 Gr. 50
L-1	IR-254 mm x 32.8 kg/m	A-572 Gr. 50

Results

As shown in **Figure 1**, it can be observed that the analysis includes three phases, which consists of a numerical procedure or mathematical formulation whose fundamental objective is the determination of forces or stresses, displacements or deformations of a structure subjected to loads and their combinations, while the structural design involves the selection of the material, the dimensioning of the components of the structural system that allows it to adequately and rationally support the acting forces, in order to fulfil the function for which it was conceived. Although these two aspects of structural engineering are often studied in separate courses, in professional practice they are strongly linked and are carried out through iteration until a project that complies with the design philosophy is achieved.

The structural analysis and design of this project covers a section of the stadium, from the foundations to the stands. All the elements that make up the stadium system such as the footings, steel slab system and stands including the beams and columns will be designed in accordance with AISC-ASD (AISC, 1989). The strength will be obtained by means of the computer aided linear analysis, Staad-Pro, and therefore the value judgement regarding the structural behaviour of the elements that make up the stadium required to fulfil the objective entrusted by the client will be obtained from the result obtained.

In its initial stage, the analysis of a structure is detonated from the knowledge of the preliminary dimensions of all its elements (Tahir & Ghafoor, 2023). This preliminary design is often based on a more or less crude or simple analysis, and is influenced by the engineer's experience and judgement. Having determined an initial set of member sizes, a more detailed analysis can be made to determine forces and displacements using equilibrium, kinematic, constitutive and compatibility equations. Equilibrium equations establish relationships between the forces acting on the system and can be classified into static and dynamic. Kinematic equations relate displacements to deformations, constitutive equations relate stresses to deformations and compatibility equations relate deformations to displacements (Chen *et al.*, 2005). **Figure 2** shows the axial load resulting from the loading scenarios, where the red lines represent compression and the blue lines represent tension.

Box 5

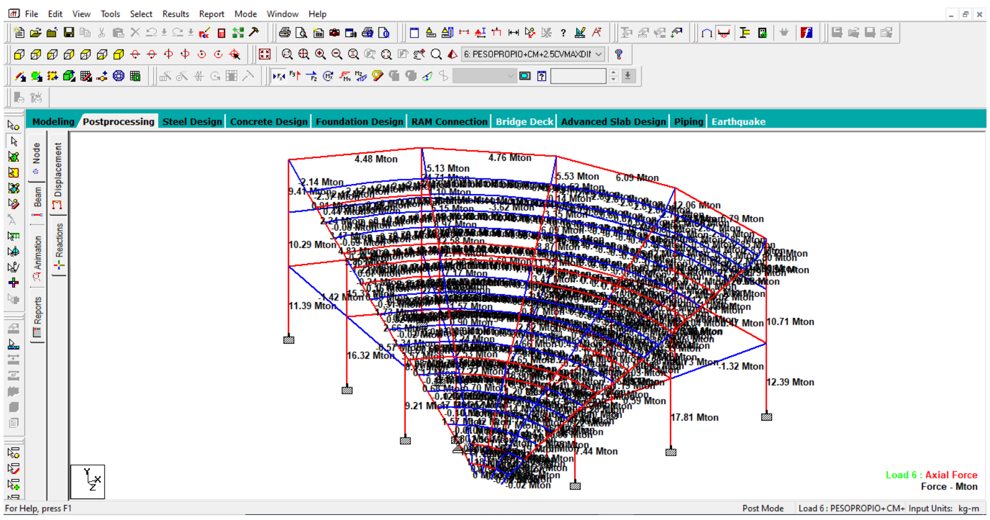


Figure 2

Maximum axial load, 47.6 ton

Figure 3 shows the shear force diagram produced by the load scenarios, which is a graph that shows the behaviour of the internal force of the beams produced by the effects of the external forces over their entire length (Hibbeler, 2012). When modelling a structure, the geometry, the type of material and the acting loads with their critical scenarios are defined a priori. The definition of the geometry includes specifying at which points and in which degrees of freedom the value of the displacement is known, in this case referring to the supports, this being defined as everything in which the value taken by one or more of its degrees of freedom is known, i.e. every point of known displacement is called a support. This value may be zero or non-zero.

Box 6

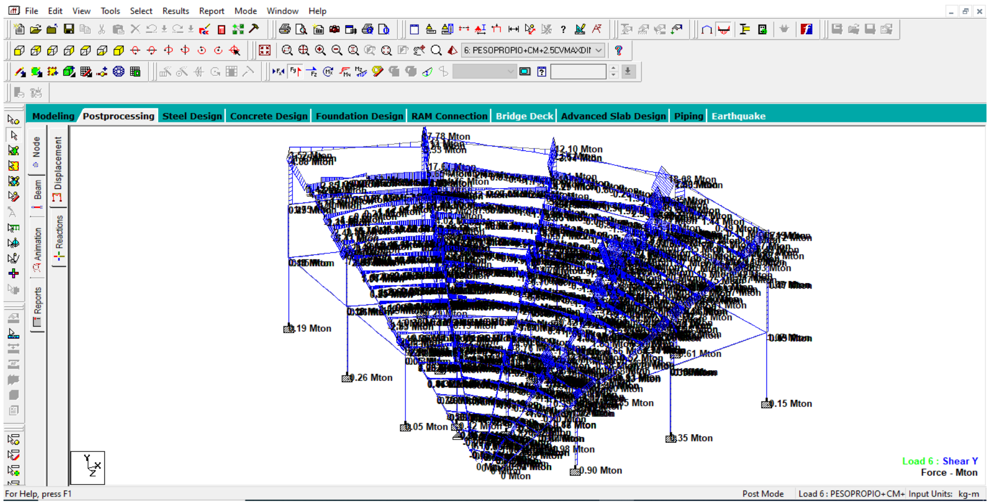


Figure 3

Maximum shear, 24.30 ton

Figure 4 shows the bending moment diagram resulting from the loading scenarios. This graph represents the moment produced due to external loads (Kassimali et al., 2015).

Box 7

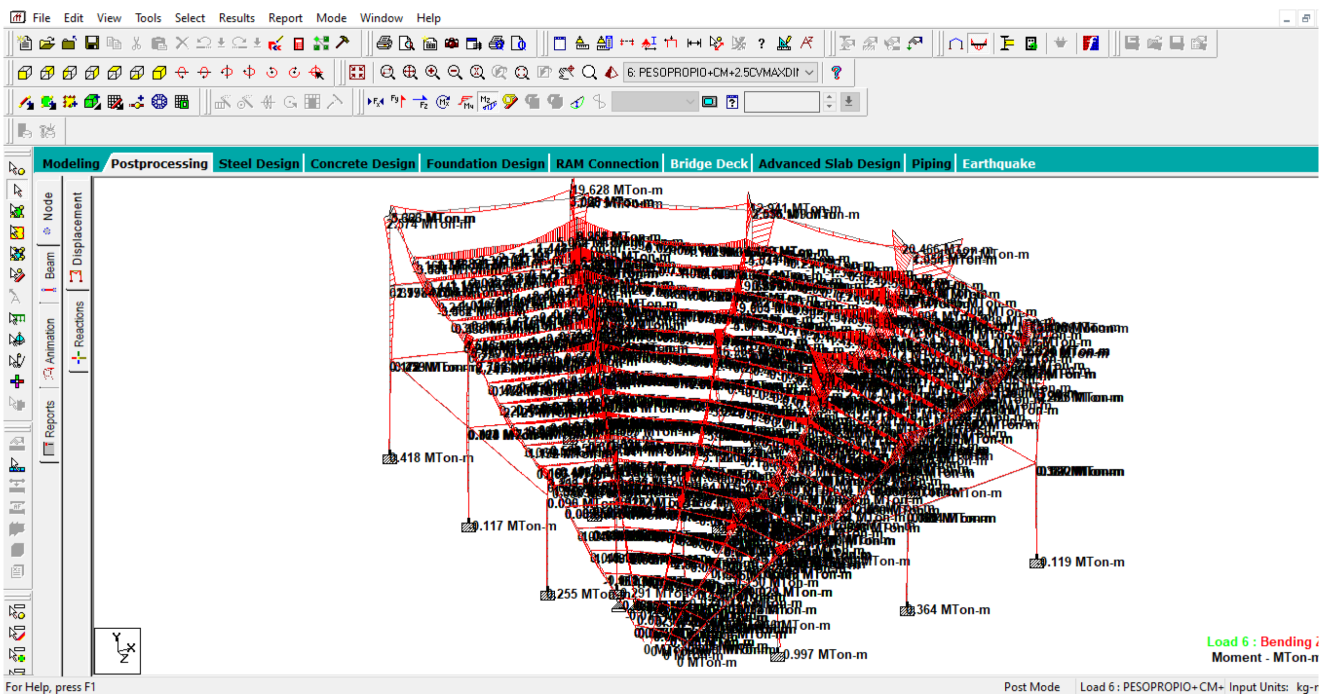


Figure 4

Maximum bending moment, 24.90 ton-m

Figure 5 shows the interaction ratio in which the ultimate acting magnitude is divided by the resistance. Note that it exceeds the optimum magnitude of 0.8, which implies that in a deteriorated state it needs to be strengthened.

Box 8

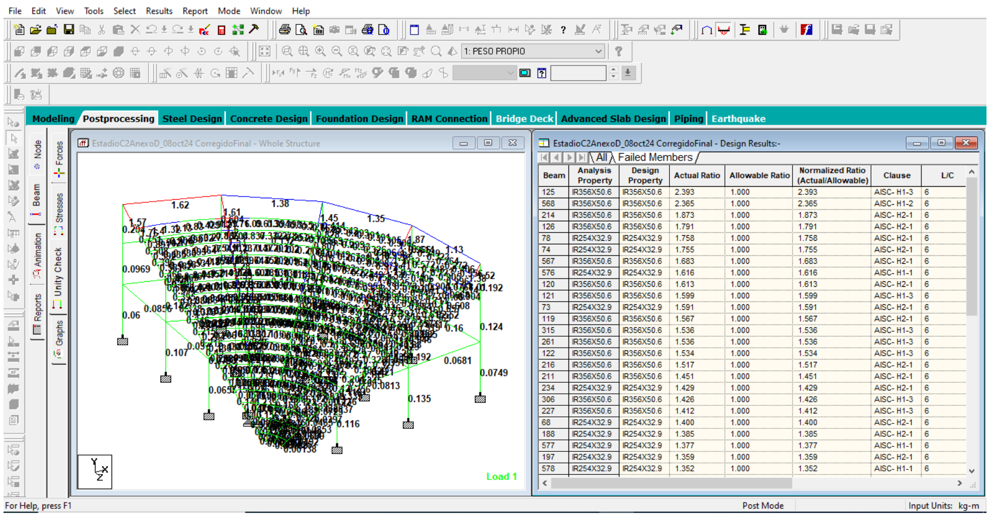


Figure 5

Failure limit state, 2.93

Figure 6 shows the maximum deformation in the structure. It is observed that a maximum magnitude of 8.92cm is present, which exceeds the tolerance, which should be reinforced to ensure structural safety.

Box 9

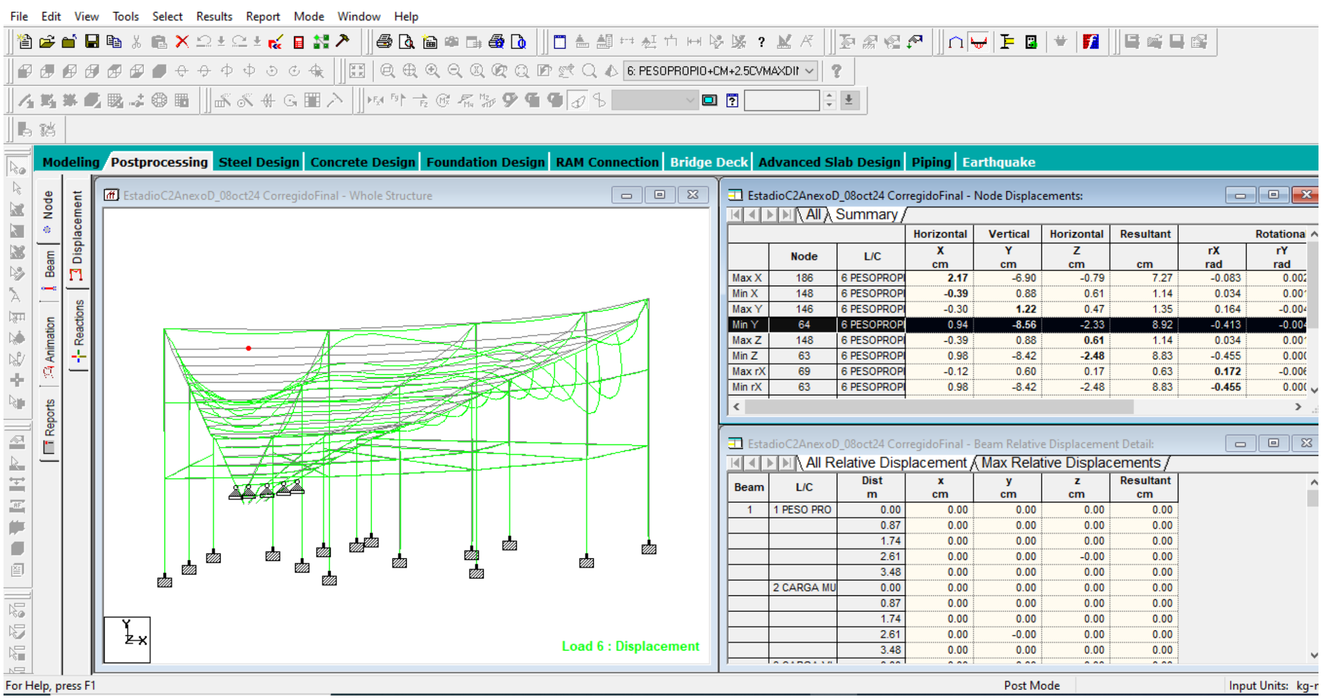


Figure 6

Serviceability limit state, 8.92 cm

Conclusions

When generating results, it is concluded that the structure does not comply with the limit states, understanding that a limit state of behaviour is reached in a construction when a combination of forces, displacements, fatigue levels, or several of them, which determines the onset or occurrence of an unacceptable behaviour mode of such construction, is present (NTC, 2023). According to the Regulation, such limit states are classified into two groups: failure limit states and serviceability limit states. The former involve the occurrence of behavioural modes that endanger the stability of the construction or part of it, or its ability to resist new load applications. The latter include economic damage or the occurrence of conditions that prevent the proper performance of the functions for which the construction was designed, resulting in a result shown in equation [1]:

$$\Delta_{m\acute{a}x} = \frac{L}{240} = \frac{551\ cm}{240} = 2.30\ cm \qquad [1]$$

It is recommended to reinforce the structure at the points shown in Figure 7.

Box 10

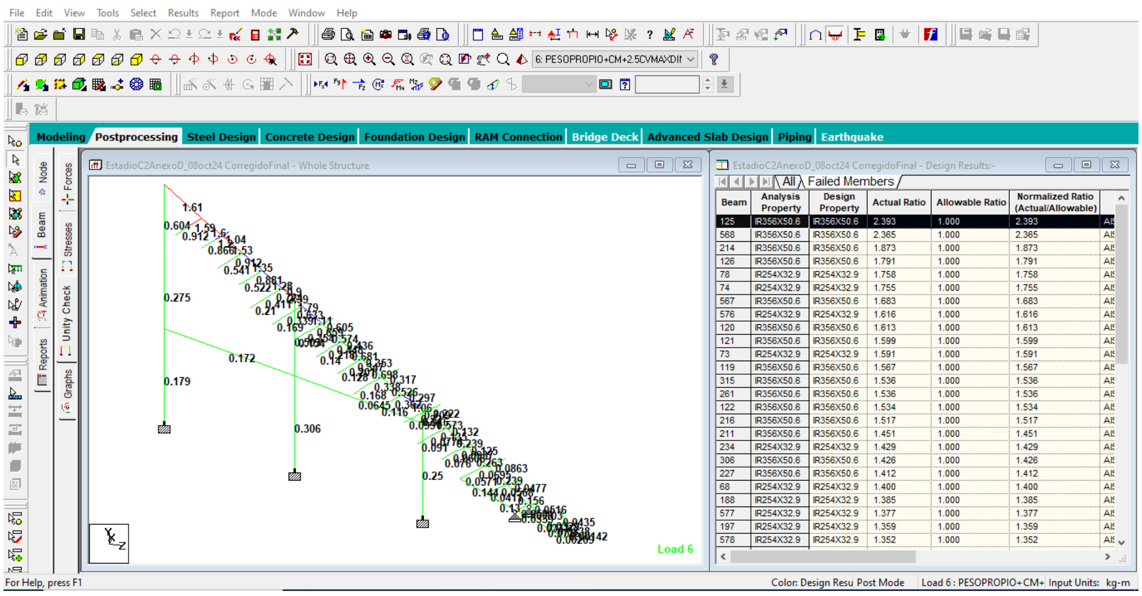


Figure 7
Recommended reinforcement

Annexes

Declarations

Conflict of interest

The authors declare that they have no conflicts of interest. They have no financial interests or personal relationships that could have influenced this book.

Authors' contribution

The contribution of each researcher to each of the points developed in this research is:

Gutierrez-Can, Yuriko: Contributed to the data collection and as-built drawings analysis.

Palemón-Arcos, Leonardo: Carried out the modelling, simulation, analysis and structural design.

Naal-Pech, José Wilber: Contributed to the determination of thicknesses of profiles damaged by corrosion.

Álvarez-Arellano, Juan Antonio: Contributed in data processing and application technique.

Availability of data and materials

The data obtained in this research is available at any time it is required.

Funding

This research did not receive any funding.

Acknowledgements

The authors, Yuriko Gutiérrez-Can, Leonardo Palemón-Arcos, José W. Naal-Pech and Juan Antonio Álvarez Arellano, gratefully acknowledge the support of the Consejo Nacional de Humanidades, Ciencias y Tecnologías (CONAHCYT), as well as the Programa para el Desarrollo Profesional Docente (PRODEP) through the Grupo Disciplinar Ingeniería Estructural Aplicada e Ingeniería de la Construcción y sus Procesos Sustentables provided through the Universidad Autónoma del Carmen (UNACAR).

Abbreviations

CFE	Federal Electricity Commission
INEEL	National Institute of Electricity and Clean Energies (Instituto Nacional de Electricidad y Energías Limpias)
NTC	Complementary Technical Standards
W	Average load
Wa	Instantaneous load
Wm	Maximum gravitational load

References

Background

AISC Manual Committee, & American Institute of Steel Construction (1989). *Manual of Steel Construction: Allowable Stress Design*. American Institute of Steel Construction.

Fuentes, J. C. N., Granados, P. A., & Martins, F. C. (2018). Integrated coastal management in Campeche, Mexico; a review after the Mexican marine and coastal national policy. *Ocean & coastal management*, *154*, 34-45.

Tahir, F., & Ghafoor, L. (2023). *Structural Engineering as a Modern Tool of Design and Construction* (No. 10051). EasyChair.

Chen, W. F., & Lui, E. M. (2005). *Handbook of structural engineering.* CRC press.

Basics

Sun, H., Yang, M., & Wang, H. (2022). Resilience-based approach to maintenance asset and operational cost planning. Process Safety and Environmental Protection, 162, 987-997.

Hibbeler, R. C. (2012). *Structural analysis.* Pearson Mexico.

Kassimali, A., Galán, A. A. A. A., & Mellado, J. F. H. (2015). *Análisis estructural*. Cengage Learning.

Support

Van Coile, R., Jovanović, B., Put, F., (2024). Reliability-based safety format for structural fire engineering - Derivation based on the most likely failure point, Journal of Infrastructure Intelligence and Resilience.

NTC, D. (2023). Complementary technical standards on criteria and actions for the structural design of buildings. *Official Gazette of Mexico City*, *CDMX*.

CFE. (2020). Manual de Obras Civiles de Comisión Federal de Electricidad, Diseño por Viento. (MOC-CFE-DV-2020), Instituto de Investigaciones Eléctricas, Cuernavaca, Morelos; Mexico.

CFE. (2015). Manual de Obras Civiles de Comisión Federal de Electricidad, Diseño por Sismo. (MOC-CFE-DS-2015), Instituto de Investigaciones Eléctricas, Cuernavaca, Morelos; Mexico.

Wu, H., Lei, H., & Frank, C. Y. (2021). Study on corrosion models of structural steel exposed in urban industrial atmospheric and laboratory simulated environments based on the 3D profile. *Thin-Walled Structures*, *168*, 108286.

Sarath, C. V. K., Kumar, K. A., Lingeshwaran, N., VigneshKannan, S., & Pratheba, S. (2020). Study on analysis and design of a multi-storey building with a single column using STAAD. Pro. *Materials Today: Proceedings*, *33*, 728-731.

Kostic, S., Miljojkovic, J., Simunovic, G., Vukelic, D., & Tadic, B. (2022). Uncertainty in the determination of elastic modulus by tensile testing. *Engineering science and technology, an international journal*, *25*, 100998.

Differences

Yelamasetti, B., Sonia, P., Aslesha, C. L., Vardhan, V., Ahmed, F., Kumar, A., ... & Alnaser, I. (2024). Investigations on corrosion rate, mechanical properties and structural homogeneity of interpulse TIG dissimilar weldments. *Journal of Materials Research and Technology*, *32*, 2537-2546.

Discussion

Daou, H., Raphael, W., Chateauneuf, A., & Geara, F. (2019). Probabilistic Assessment of Structural Safety of Complex Structures-Application to Terminal 2E at Roissy, CDG Airport. *Procedia Structural Integrity*, *22*, 17-24.