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OPEN-SOURCE SOFTWARE DEVELOPMENT FOR THE ASSISTANT OF STRUCTURAL DESIGN PROCESS IN ETABS, APPLYING COLOMBIAN SEISMIC NORMATIVE NSR-10.

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abstract: In the academic and professional field of civil engineering, software development is essential for efficiency and precision in structural design of buildings. In this context, an open-source software is created that acts as an assistant in structural design using ETABS as the main tool, to improve efficiency and precision in the design process, applying the Colombian standard NSR-10. As a result, an exemplary report of a beam design with special energy dissipation capacity is generated. This type of software allows civil engineers to have access to a quality tool, adaptable to their specific needs, leading to better performance in their work and greater competitiveness in the market.

*Keywords.*ETABS, software development, open source, civil engineering, assistant, structural design, NSR-10

1. Introduction

Historical analysis of human development reveals that the Industrial Revolution marked the first significant inflection point that propelled humanity's progress. Meanwhile, the evolution of computing stands as the second major revolution, driving changes of comparable magnitude [9]. However, the rapid pace of technological advancement has led to accelerated knowledge obsolescence [10], with predictions suggesting approximately 47% of occupations face substantial automation risks [12]. Nevertheless, open access to technology democratizes its reach and enables adaptation to individual needs while strengthening information security management [11].

In the engineering field, particularly in seismic-resistant structural engineering, strict adherence to the guidelines outlined in the NSR-10 Seismic Resistant Standard (Norma Sismo Resistente) is imperative to ensure robust design and construction against seismic events. Roberto Rochel Awad [7] conceptualized the methodology for configuring earthquake-resistant structures following the Colombian NSR-10 regulations. Similarly, Jack McCormac [6] presented the calculation methodology for structural components.

Anticipating these needs, the Colombian government not only established legal frameworks for seismic-resistant construction but also promoted Information and Communication Technologies (ICT) adoption through the National ICT Plan (PNTIC) to enhance competitiveness and achieve broader

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social integration [5]. Currently, in structural engineering practice, specialized tools provided by Computers and Structures, Inc. (CSI) have become standard. Among these, the Extended Three-dimensional Analysis of Building Systems (ETABS) software stands out for offering more comprehensive functionalities compared to alternatives [8].

Technological research in civil engineering tends to focus on method optimization and the development of support tools that automate technical and theoretical processes, which is crucial. However, these investigations often fail to comprehensively cover the entire design process. The availability of open-source code in these technologies enables rapid integration into professional environments and fosters civil engineers' competitiveness and adaptability to individual requirements. Such research contributes to efficiency, problem-solving, innovation, and technological advancement in civil engineering.

The labor sector is expected to continue implementing process automation measures to enhance competitiveness by optimizing work timelines and minimizing human errors [15]. Reinforced concrete frame construction is widely used in civil engineering and requires agile design approaches to improve Colombian engineers' competitiveness while reducing errors in structural conceptualization and design. Simultaneously, integrating accessible technological advances adaptable to engineers' specific needs drives economic and social development through Information and Communication Technologies (ICT).

This research develops a software tool that enables civil engineers to streamline the structural design process for reinforced concrete frame buildings. Considering that structural building design requires not only in-depth analysis of effects on each structural defense system component but also compliance with national regulatory standards.

2. Methodology

The research design adopted in this study is non-experimental, and the methodology is characterized as applied in nature. This indicates that the focus of the research is not to manipulate variables in a controlled environment, but rather to address real-world problems through the practical application of theoretical knowledge. The objective is to obtain a concrete and useful result that contributes directly to the professional practice of civil engineering.

Data collection was carried out through a technique known as *card indexing*, which involves the systematic gathering, classification, and storage of information from various sources. Both digital and physical resources were utilized, allowing for an efficient organization and systematization of relevant content. This approach ensures that the information used in the development of the software is accurate, traceable, and well-documented.

The creation of the computer program followed a systematic and structured development process. This process involves the design and implementation of algorithms capable of processing, storing, and manipulating data to achieve a specific goal. The final result is the product of a sequence of interrelated sub-processes, in which each algorithm performs a specialized function, contributing to the integrity and performance of the overall system.

This methodological approach ensures that each phase of development—from the initial analysis of user requirements to the final validation of the software—is carried out in alignment with the technical standards and practical demands of the structural branch of civil engineering. Furthermore, it promotes a logical flow of tasks and maintains consistency between the theoretical models and their practical implementation.

Figure 1 presents the proposed methodology for technological development in the structural area of civil engineering. It details the key phases including requirements analysis, algorithmic design, implementation, verification, and validation of results. This methodological framework reflects a comprehensive approach that balances theoretical rigor with practical application, ensuring that the final software product is both effective and applicable in real-world professional scenarios.

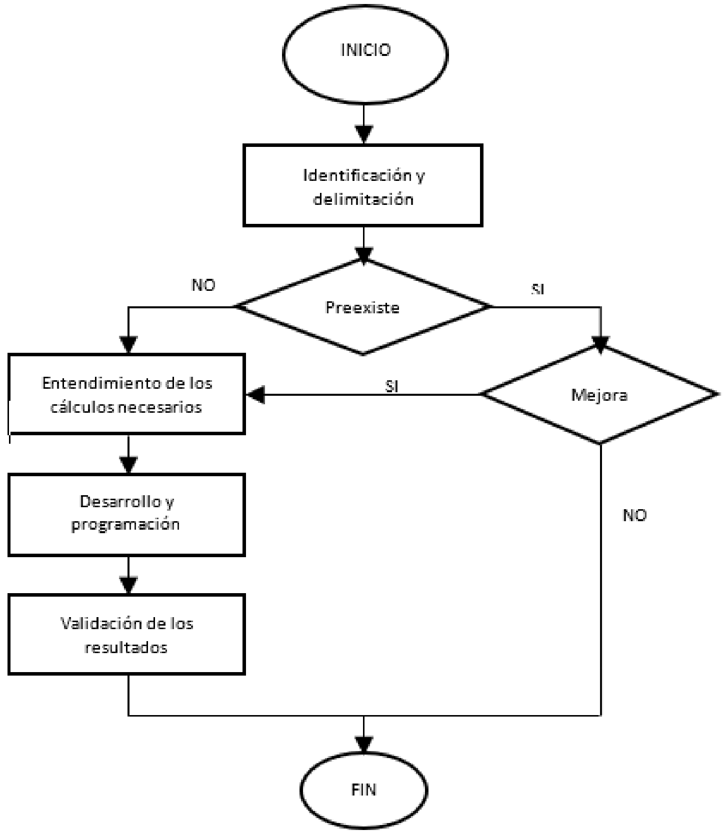

FIGURE 1. Proposed methodology for software development in structural civil engineering.

3. Results

3.1. Developing an Open-Source Program. Python was used as the main programming language, along with QML and SQL, to create AEUS (Structural Assistant, University of Sucre) as software adaptable to the specific needs of users, thanks to the release of its code in an open format, which in itself constitutes supplementary documentation.

The use license for the AEUS application code is governed by the terms and conditions of the license created by the Free Software Foundation: the GNU General Public License, version 3 or any later version.

FIGURE 2. GNU. Taken from [11]

3.2. Designing an Intuitive and User-Friendly Interface for Data Input and Results Visualization. The data input and visualization process was conceived with a focus on the usefulness of the program as an auxiliary tool in structural design, where the main software is ETABS. Therefore, a minimalist and intuitive interface was designed, allowing the user to enter data easily and obtain accurate and concise results. The following figure shows the application's welcome screen.

This introductory section includes space for the project name, its description, applicable design standards, tools used, the person in charge, and the work team. Afterwards, the general data section is presented, in which the fundamental parameters of the project are established to achieve appropriate preliminary design and seismic-resistant analysis based on the equivalent horizontal force.

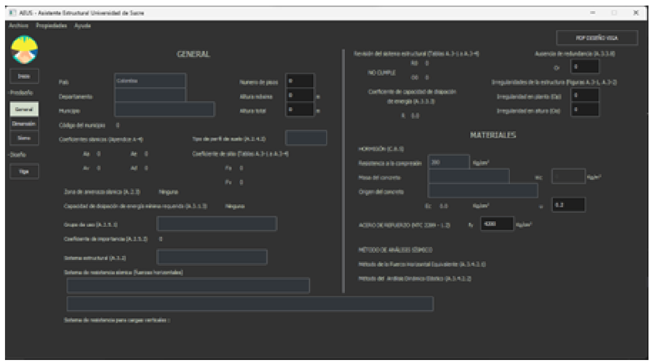

FIGURE 3. General data section. Own work

In this section, the project's geographical location is defined, which provides essential information such as seismic coefficients, enabling proper energy dissipation. Additionally, other relevant data are collected, which will be highly useful in the following phases of the project, as well as the input data required for accurate modeling in the ETABS software. In the preliminary design section, for moment-resisting frame systems with any required energy dissipation capacity, beams, columns, and one-way slabs are preliminarily designed.

FIGURE 4. Preliminary design section for beams, columns, and one-way slabs. Own work

It is important to highlight that for an adequate preliminary design of columns, the corresponding section must be used to determine live loads and, in this way, calculate the preliminary dimensions of both interior and exterior columns on any floor. In the seismic analysis section, loads are established based on the applicable standards and are justified through the corresponding analysis. Additionally, the calculation of the equivalent horizontal force is carried out, which is essential in both static and dynamic seismic analyses.

FIGURE 5. Load section, load justification, and equivalent horizontal force calculation. Own work

Finally, in the design section of a reinforced concrete moment-resisting frame beam, the results obtained from analysis using specialized programs such as ETABS are used to determine the shear forces and moments of the beam to be designed. With these data, the final beam design is carried out. Appropriate types of steel must be selected to meet each strength requirement, considering a strategic distribution from a constructive perspective.

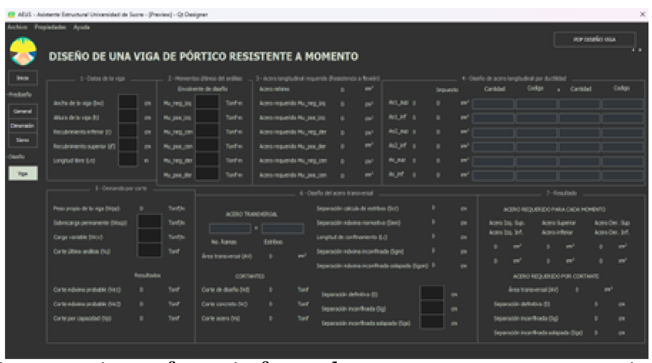

FIGURE 6. Design section of a reinforced concrete moment-resisting frame beam. Own work

The graphical interface provides the user with a means of communication with the application, thereby establishing the boundaries and capabilities of the system, helping to define its functionality. The AEUS interface focuses on specific data and concrete results, empowering the user over the generated information.

3.3. Preliminary Design of Beams, Columns, and One-Way Slabs in a Reinforced Concrete Frame System Using the Developed Program. To carry out the preliminary design of structural beams, columns, and one-way slabs in a reinforced concrete frame system, it is first necessary to define the structural resistance system and energy dissipation capacity of the building. This requires knowing the project's location, and in accordance with the NSR-10 (Colombian Seismic Code) as cited in each section, the compliance of the selected resistance system must be verified.

Seismic coefficients and required energy dissipation. The first step is to select the department and municipality. Based on this input, the program will provide essential information including the municipality code, corresponding seismic coefficients, seismic hazard zone, and energy dissipation requirements for the project.

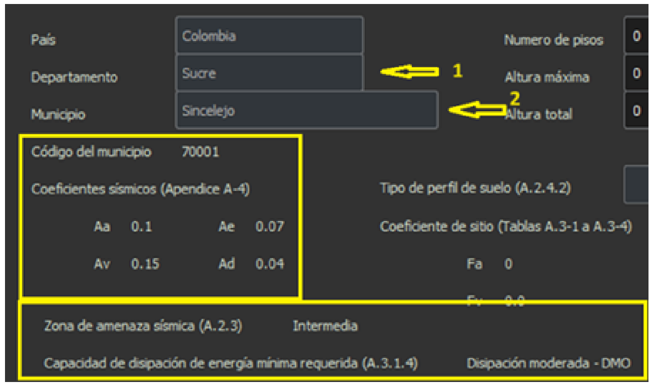

FIGURE 7. Seismic coefficients. Own work

Importance factor. The appropriate occupancy/use group must be specified. Once this data is entered, the program will generate the corresponding importance factor for the project.

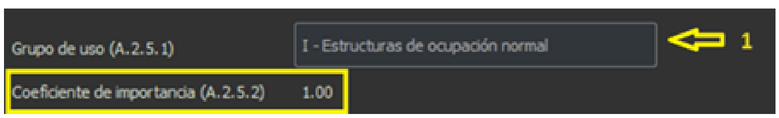

FIGURE 8. Importance factor

Structural system review. Initially, it is essential to define the number of stories in the building, as well as the maximum interstory height and the total building height.

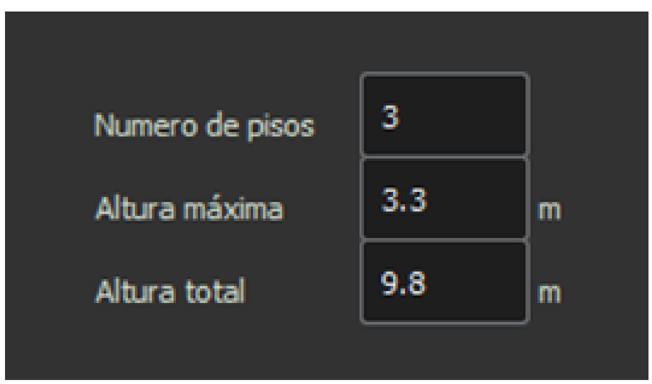

FIGURE 9. Building height

On the left side of the general data section, the structural system must be specified, which will determine the horizontal seismic resistance system. The program will provide information about the required vertical resistance system and will perform an exhaustive verification of compliance with the selected structural system.

The program verifies compliance using the tables established by the Colombian NSR-10 code. It uses the provided data, which includes the required energy dissipation level for the project, number of stories, maximum interstory height, and total building height.

FIGURE 10. Structural system compliance

It is worth noting that the general section also establishes the basic concrete parameters for reinforced elements.

Structural materials. To allow the program to determine the modulus of elasticity of the concrete, it is necessary to specify the compressive strength to be used. Information about the mass and origin of the concrete must also be provided. Based on this, the program calculates the steel yield strength according to the applicable standard and provides Poisson's ratio.

FIGURE 11. Material considerations in reinforced concrete structures. Own work

Preliminary design framework. Once the essential data related to the seismic resistance system and energy dissipation capacity have been determined, the preliminary design of structural components such as beams and columns in the reinforced concrete frame system can be carried out.

It is important to note that the dimensions obtained at this stage are preliminary. Final dimensions must be calculated using specialized software like ETABS. However, estimating these dimensions early allows for fewer design iterations, leading to significant time savings during the design process.

FIGURE 12. Preliminary design framework

Knowing the architectural layout of the building, the basic frame system must be outlined, consisting of placing only the main beams and columns on the floor plan, and then adding the one-way slabs, if applicable.

Preliminary design of beams. The required dimensions—whether simply supported, continuous at one or both ends, or cantilevered—must be entered into the program to calculate the appropriate beam height using the tables provided by NSR-10. The beam width is estimated based on the recommended minimum, related to the energy dissipation capacity. As a general rule, it is taken as half of the beam height. In the example, since moderate energy dissipation (DMO) is used, a minimum width of 20 cm is required.

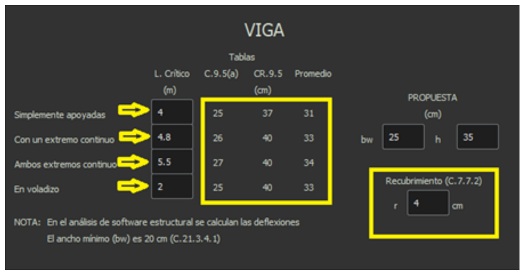

FIGURE 13. Preliminary beam design

The program uses Tables C.9.5(a) and CR.9.5 and displays the results of both. It also offers the option to show the average of the two. Using the average may be beneficial in some cases as it can provide a closer estimate to the final desired height. Choosing between individual or average results is up to the designer. Final dimensions, including deflection checks, will be performed in ETABS.

For main beams—those supporting ribs in a lightweight slab or carrying loads from a solid slab—the base width should be greater than the minimum recommendation and exceed half the beam height. Depending on the design, it may be appropriate to preliminarily estimate the width as equal to the beam height.

Preliminary design of one-way solid slab. As with beams, the same input data is required. The same tables from the code are used, but from a different section. This means different results will be obtained even with the same input, as the context applies specifically to solid slabs and their influence area.

FIGURE 14. Preliminary design of one-way solid slab

Preliminary design of one-way lightweight slab. The same data required for beams is used. The same tables are applied, meaning that the same values are obtained.

FIGURE 15. Preliminary design of one-way lightweight slab

The difference lies in the fact that no base width needs to be defined, since this is not a beam. Once the height has been estimated, in the one-way lightweight slab section, the orientation of the ribs must first be defined. This step determines the minimum thickness of the topping and the minimum rib width. After the desired rib width is set, the software calculates the maximum free height for the ribs. It also determines the maximum allowable spacing between ribs and the required spacing for bracing ribs.

FIGURE 16. Preliminary design of one-way lightweight slab

Preliminary design of columns. Minimum dimensions for each column are determined based on the selected energy dissipation capacity. Longitudinal reinforcement area must be between 1% and 4% of the column's cross-sectional area. Preliminary sizing for a column at a given level involves defining the number of stories above that affect the column, and detailing its location within the structural context.

The AEUS program performs preliminary sizing considering several key factors, including the tributary area of the column, beams delivering loads to it, and the length of those beams. It also accounts for interstory live loads acting on the tributary area. Based on these inputs, the program generates square preliminary dimensions to guide the designer. However, the final decision rests with the designer, who must make informed choices to determine the required minimum longitudinal reinforcement.

3.4. Establishing Design Loads Required for Structural Design in ETABS Using the Developed Program. To accurately formulate the mathematical model in the specialized ETABS platform and precisely estimate the initial dimensions of the columns, it is imperative to consider loads beyond the self-weight of the structural elements present in the building. In this regard, various sections of the Colombian seismic code provide guidelines for obtaining these additional loads. Moreover, specific calculations are required to precisely determine the loads due to partitions and interstory leveling mortar.

The load generated by staircases is derived from the tread and riser dimensions, while live loads are established according to the provisions of the code.

Regarding the calculation of the Equivalent Horizontal Force (EHF), it is essential that the general section has previously defined the seismic coefficients, site coefficients, and energy dissipation capacity coefficient. These parameters play a fundamental role in the structural analysis and design process, ensuring a rigorous and scientific approach to evaluating the seismic response of the building.

FIGURE 17. Load framework and EHF

Leveling mortar justification. To calculate interstory loads, it is essential to first establish the thickness of the mortar used for leveling. This thickness typically averages around 4 centimeters. Variations in this measure may be due to various factors, one of the most relevant being the need to conceal plumbing. For example, if pipes with an external diameter of approximately 2.6 centimeters are used, a 4 cm mortar thickness will be sufficient to effectively cover them.

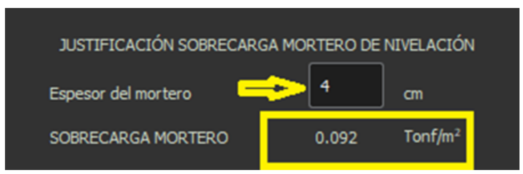

FIGURE 18. Justification of leveling mortar load

Partition load justification. Calculating the load from partitions requires specific information such as the total length of walls, their height and thickness, and the total area of the slab. With these data, it is possible to determine the distributed load imposed by the walls on the slab, which allows for accurate estimation of the partition load. This detailed analysis is crucial for adequately assessing the applied loads and ensuring a reliable structural design.

FIGURE 19. Partition load justification

Interstory loads. Based on the justifications provided, the next step is to define the interstory loads. The code provides minimum load values in various sections, which must be compared to the justified loads. If there are additional loads not covered by the code, they must be recorded in the section labeled "others."

FIGURE 20. Interstory load

Stair load. Determining imposed loads on a staircase requires knowledge of two fundamental parameters: the tread and riser dimensions. With this information, it is possible to calculate the load generated by the mass of the reinforced concrete forming the steps and resting on the stair slab. This analysis considers both the staircase geometry and the material of the steps, ensuring a precise evaluation of the additional loads that must be considered in structural design.

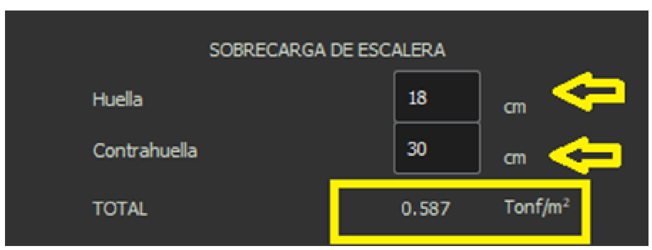

FIGURE 21. Stair load

Live loads. To estimate live loads, the seismic design code is used as a reference.

FIGURE 22. Live load

3.5. Perform Seismic Analysis Using the Equivalent Lateral Force Method for Structural Design Using the Developed Program. The base data for seismic analysis is located in the general section, where it is necessary to define the soil type and the structural irregularities.

Energy Dissipation Capacity. After verifying the compliance of the structural system and obtaining the initial energy dissipation capacity coefficient, it must be multiplied by each of the irregularity and redundancy factors. These values must be determined manually and then verified in ETABS, since the AEUS program lacks information about the building model and therefore cannot determine the presence or absence of structural irregularities.

Although AEUS lacks detailed information about the building model, it provides the final result for the energy dissipation capacity coefficient once the manually calculated irregularities and redundancies have been accounted for.

Site Coefficients. At this stage, the program already contains the necessary information, including seismic coefficients, which allows it to calculate site coefficients simply by establishing the soil profile type of the project.

Equivalent Lateral Force – ELF. Calculating the Equivalent Lateral Force is a fundamental step in structural design. To perform this calculation accurately, it is first necessary to establish the direction of the horizontal forces. The values of "Ct" and "a" vary depending on the structural system used. In the case of the AEUS program, which focuses on moment-resisting frame systems, it is reasonable to assume that the default values are always adapted to this system. However, the program offers flexibility to modify these values according to user needs and specifications.

The program calculates the coefficients for maximum period, approximate period, initial period, short period, and long period. These are essential for seismic response analysis and structural design. Knowing these periods is fundamental to ensure safe structural behavior during seismic events. Since the user is employing ETABS, it is assumed they can also calculate these periods using finite element methods or other advanced structural analysis techniques. Furthermore, knowing the fundamental period from finite element modeling is vital, as FEMA and other seismic codes often base their recommendations on this value to determine the seismic response capacity of a structure and ultimately define the design and reinforcement requirements.

By clicking the chart button, a secondary window appears showing the elastic acceleration spectrum. The full earthquake, which has not been reduced by the energy dissipation capacity, is used to evaluate inter-story drifts. This is fundamental to ensure that the deformations remain within the permitted limits.

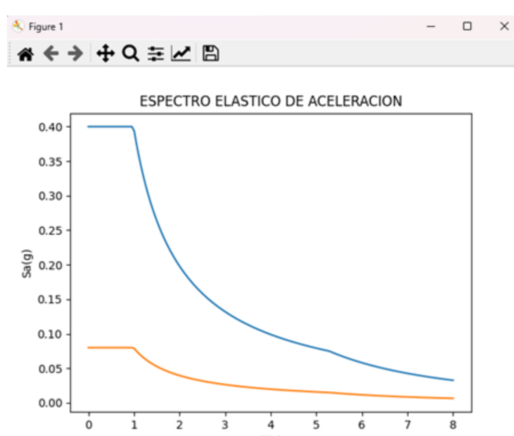

Figure 23. Elastic Acceleration Spectrum

On the other hand, the reduced earthquake is used for general structural design and analysis purposes. The reduction accounts for the structure's capacity to dissipate energy during a seismic event, resulting in a lower seismic load compared to the full earthquake. This distinction is essential to ensure both the safety and efficiency of the structural design, as it allows compliance with deformation regulations while also benefiting from the load reduction enabled by energy dissipation capacity.

3.6. Design a Beam in a Moment-Resisting Reinforced Concrete Frame with Special Energy Dissipation Capacity, Complying with the NSR-10 Code, Using the Developed Program. It is essential to develop a solid mathematical model within the ETABS environment, using finite elements as a high-precision method. This model aims to accurately determine the internal forces generated in each structural component. With detailed knowledge of the geometric properties of these elements, a beam design based on strength can be conceived by knowing the bending moments and shear forces, allowing us to determine the necessary ductile steel reinforcement.

FIGURE 24. Design of a Moment-Resisting Frame Beam

High energy dissipation capacity design imposes the most rigorous structural engineering criteria, yet it is also one of the least understood areas, making it critical to avoid design failures. Therefore, this study focuses on this area. Ultimately, many of the special design considerations are considered best practices that can be applied to less demanding designs, such as those with moderate energy dissipation capacity. The main differences between both designs, which now largely overlap in their requirements, lie in the ductility requirements of the longitudinal steel bars. These are less conservative in moderate capacity design, leading to a reduced probable maximum shear due to a lower amount of longitudinal reinforcement and, consequently, a reduced need for stirrups. In summary, a deep understanding of strength-based design in high dissipation capacity is essential for performing safer moderate dissipation designs and ensuring greater structural safety.

It is vital to emphasize that the design procedure must be executed methodically, following each step rigorously to ensure accuracy in data collection. However, it is reassuring to note that the program provides a detailed report that clarifies the internal calculation process, allowing for a thorough review and guaranteeing the integrity of the results.

Longitudinal Reinforcement. To determine the longitudinal reinforcement needed for flexural strength-based design, one begins with a thorough understanding of the beam element's geometric characteristics, including width, height, internal cover, and free length. It is also necessary to incorporate the ultimate moments obtained from the ETABS analysis. Later, shear demand must also be addressed as part of the structural analysis.

With this data, we proceed to calculate the required reinforcement ratios, which allows us to verify whether a ductile failure is possible and whether the moment capacity exceeds the applied moment.

Ductile Distribution of Longitudinal Reinforcement. Once the final bending moments experienced by the beam are analyzed, the required reinforcement for the left and right sections can

FIGURE 25. Longitudinal Reinforcement

be calculated. However, the central zone is not addressed in the previous step. This is because the properties of the steel used on the sides must first be known to accurately determine the required reinforcement in the center and ensure a proper distribution.

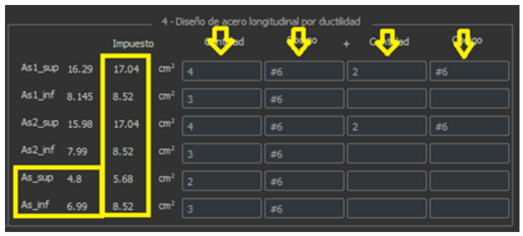

FIGURE 26. Ductile Distribution of Longitudinal Reinforcement

Transverse Reinforcement. Once all longitudinal reinforcements and applied loads are known, the maximum possible shear values are calculated. These are then compared with the ultimate shear obtained from analysis, and the higher value is used for stirrup design.

FIGURE 27. Transverse Reinforcement

Transverse Reinforcement Distribution. After calculating the design shear, the next step is to determine the required area of transverse reinforcement. To meet the minimum requirements, a

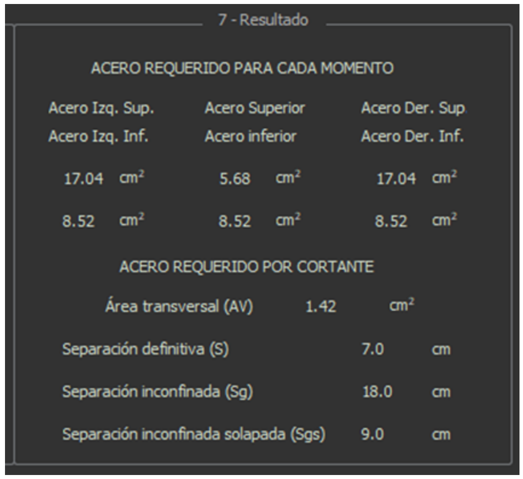

Figure 29. Beam Design Result

single closed confinement stirrup equivalent to two #3 bars with a total area of 1.42 cm^2 is used. This minimum amount is compared with the calculated minimum value, and both concrete and steel shear capacities are computed. This ultimately allows for determining the proper stirrup spacing.

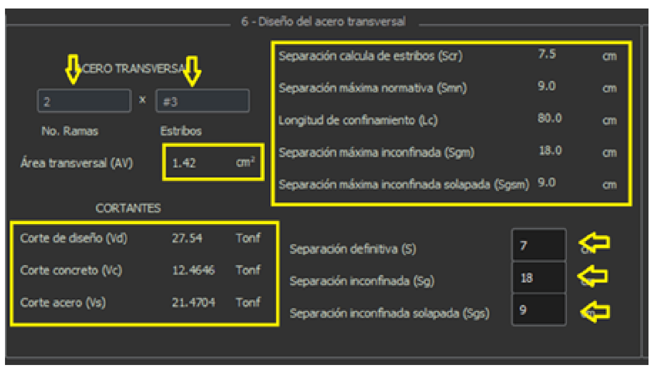

Figure 28. Transverse Reinforcement Distribution

Beam Design Result. The design result is displayed in summary form in the application's interface. AEUS uses a design approach based on ultimate strength with ductility considerations. The design process adheres to the guidelines established in the Colombian seismic design code (NSR-10). Additionally, an exemplary appendix illustrates the beam design, serving as a valuable resource for understanding the procedure implemented by the software.

3.7. Provide a Detailed Design Report for a Beam in a Reinforced Concrete Moment Frame with Special Energy Dissipation Capacity Using the Developed Program. The report contains detailed information accompanied by images that allow users to review and understand the internal process used to design a beam in a reinforced concrete moment frame with special energy dissipation capacity.

Top Bar. In this section, there is a button that, when activated, opens a secondary window dedicated to entering the information required for generating the PDF report based on the data stored up to that point.

When the button is pressed, a secondary window will open. It is important to note that the file name must end with the extension `.pdf`, otherwise the report will not be displayed with the correct format. If this occurs, the user must locate the generated file and manually rename it, adding the `.pdf` extension to view it properly.

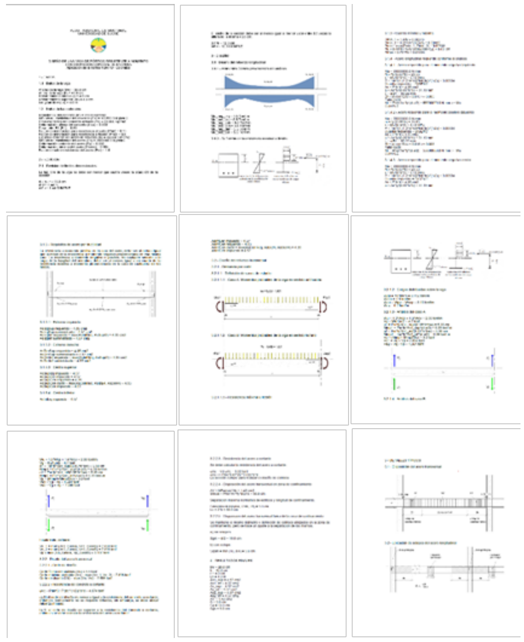

FIGURE 30. PDF Report of a Beam Design Generated by the AEUS Program

3.1. **3.8. About the Results.** An open-source program was developed to assist university students and civil engineering professionals in the structural design of reinforced concrete moment frame buildings, using ETABS as the main tool and applying the NSR-10 code. The program is called AEUS – *Asistente Estructural Universidad de Sucre*. During its development, algorithms were implemented in Python for the preliminary design of beams, columns, and one-way slabs, specifically for moment-resisting concrete frame systems, as well as the final design of a beam in such a system.

The calculation report generated by the program provides a detailed description of the beam design process, highlighting more accurate results compared to manual calculations, thanks to its ability to handle a greater number of decimal places.

The input units used are kilograms, tons, centimeters, and meters—common units in everyday use in Colombia. This choice was made deliberately to promote more effective and understandable communication between designer and client. However, in accordance with NSR-10, formulas are applied using SI units such as newtons and pascals, which are essential for the rigorous application of structural equations.

4. CONCLUSIONS

The objectives set for this project were successfully achieved, culminating in the development of the AEUS software and the release of its Python source code under the GNU GPL version 3 license or any later version. The calculation methodology used is documented in each relevant section of the code, and for beams, the design was carried out based on strength. This study represents a valuable contribution to the academic community by transparently presenting the development process of AEUS, thereby promoting knowledge democratization and fostering social inclusion through the use of information technologies.

The graphical interface was designed with a minimalist approach, focusing on presenting relevant data that enables designers to verify the design process in real time and make informed decisions.

A deliberate choice was made to require users to manually input their data, which ensures greater control over the calculation progress and provides a more interactive and participatory experience. This strategy fosters close interaction between the user and the tool, promoting informed and precise decision-making during the design process.

AEUS focuses on the preliminary design of a reinforced concrete moment frame building, providing the necessary data to perform accurate analysis in ETABS (compatible with all its versions), once the structure is correctly modeled mathematically in that software. The envelope moment and shear results obtained from ETABS enable the final design of beams using our Python-based software.

Future updates of the software will include new features and ongoing improvements, along with a technical support plan to ensure long-term sustainability. The system's learning curve has been optimized so that end users can efficiently adopt it in their professional environment, facilitating implementation and maximizing practical utility.

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