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REINFORCING APPLICATION IN AN OLD STEEL STRUCTURE BUILDING WITH THE PRE-STRESSING METHOD

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Abstract: The objective of this work is to develop an application of structural reinforcement to the building of the Institute of dairy products and fatty derivatives of the PJC in Arganda, which is configured by metal frame frames, applying a solution analyzed with the prestressing method. A structural analysis of the building was carried out to know its current behavior. With the data obtained, the case of removing a pillar on the ground floor was raised, leaving a span twice as long, this because it is a critical situation. Under these conditions, a new analysis was carried out to determine the new way of working in the building. This resulted in elements that did not meet the structural safety conditions, which is why a reinforcement design was proposed. For this, the analysis was carried out by means of matrix calculation and once its effectiveness was verified, the elements that make up the reinforcement were designed. With the results obtained, it is intended to promote the use of prestressing as a reinforcement solution in cases of metallic structure buildings and to verify that the proposed method is applicable and presents a feasible solution.
Keywords: Structural reinforcement, pre-reinforcement, structural steel, rehabilitation, old structures.

HIGHLIGHTS

- The rehabilitation of buildings has been increasing in recent years.
- More rehabilitation projects for existing buildings must be developed as a new goal at the furniture level.
- Constructive solutions must be characterized by three things: fast, economical and environmentally friendly.

HEADLINES:

- The rehabilitation of buildings has been increasing in recent years.
- More rehabilitation projects of existing buildings must be developed as a new goal at the furniture level.
- Constructive solutions must be characterized by three things: fast, economical and friendly to the environment.

INTRODUCTION

The rehabilitation of buildings has positioned itself in recent years as the future of construction, due to its positive influence on the environmental impact, which compared to the creation of new projects is much lower. In the same way, rehabilitation allows old buildings to give spaces to new purposes or it can also be those that were intended from the beginning, but with the assurance that the building complies with the structural safety imposed by current regulations, this, with the purpose of to preserve the integrity of the people destined to occupy these spaces.

These buildings over the years have been losing their resistant capacities, either only due to the natural wear factor or external factors such as natural events, which presents the need to carry out a reinforcement, which means improving the characteristics of the buildings. structural elements in their rigidity, load capacity and ductility [1].

Likewise, in the current era in which we live, the areas available to create new constructions have been depleting due to the exponential growth of the population. Likewise, the possibility for the new generations to access real estate has been reduced due to the high costs out of the reach of the majority of people. And on the other hand, the environmental impact generated by the construction sector is one of the most alarming since it represents 38% of global CO_2 emissions into the atmosphere [2].

Due to these situations, rehabilitation projects of existing buildings must be developed that, through reinforcement, can be adapted for new uses. Economically, the cost of a new space vs. the cost of a rehabilitated space is much lower, because less personnel, less time and less materials are involved. On the other hand, the carbon footprint would decrease making these projects more friendly to the environment [3].

The prestressing reinforcement method has been presented as a practical solution when applying it [4]. That is why for this work it has been selected for the development of the raised topic. This method presents all the qualities that are sought for this particular case, which is why it justifies its use.

In the same way, it is intended to develop a design with a method that has not been widely applied due to lack of knowledge in the sector or the lack of confidence of professionals in the face of the unusual, so it is expected that this work will serve as a basis for future projects [5].

The objective of the research is to carry out the design of a reinforcement of structural elements of an old steel building using the prestressing methodology.

A STRUCTURAL ANALYSIS

The Institute of Dairy Products and Fat Derivatives of the PJC in Arganda, Spain was a building that was used for the research and development of dairy products and their derivatives. The building is located 24 km from the center of Madrid, in the Arganda experimental center of the Juan de la Cierva Board. Its year of construction was 1973, so the building has 49 years of life. It was conceived as an industrial building using a structural system of frames composed of hollow metal pillars for the vertical elements and double beams for the horizontal elements and the floors are mixed [6].

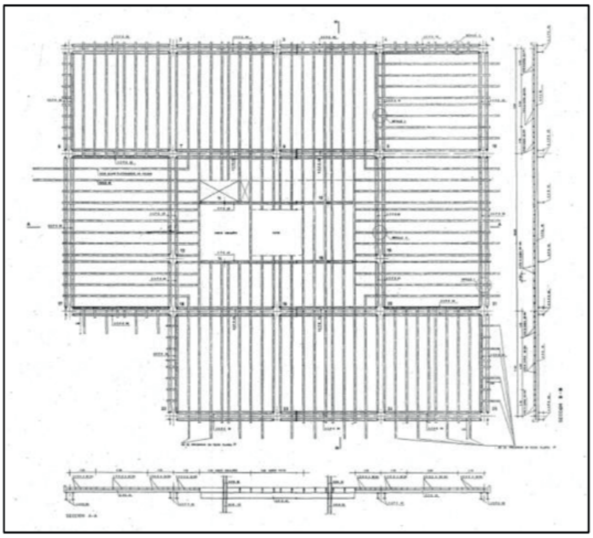

Illustration 1: Layout of the Dairy building floor plan.

The project focuses on the development of structural reinforcement with a post-tensioning system for the case where a pillar of the ground floor of the structure is eliminated, maintaining those of the upper floors, with this we simulate a case of reconfiguration of spaces where the objective is to achieve greater free light. The guidelines of the CTE-DB-SE were used since the intention is that the structure has a future use and for that the requirements of the technical regulations must be met [7].

To carry out the analysis of the initial state from which the efforts to base the reinforcement were obtained, a system was modeled based on the limit states of which it is considered that the structure does not meet some structural requirements for which the building was raised.

The following procedure was followed to carry out the analysis and dimensioning of the structure:

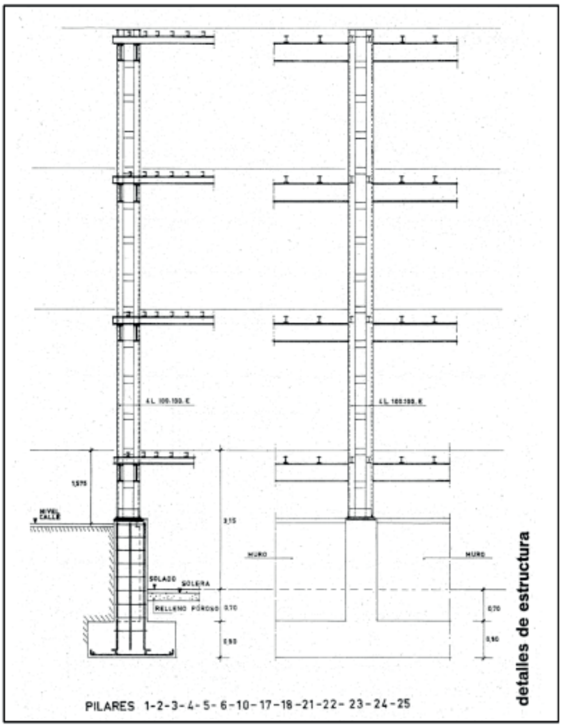

Illustration 2: Configuration of columns in the Dairy building.

- Modeling of the structure based on the original plans.
- Determination of present actions.
- Structural analysis in the SAP2000 calculation program and obtaining acting forces.
- Development of reinforcement.
- Reinforcement design.

Work was done based on the original plans obtained from the publication in the Informes de la construcción magazine; Volume 26, No 253 of the year 1973.

The horizontal structure is made up of main composite beams formed by two IPE500 beams along the perimeter and two IPE400 beams inside. For the area of the openings, the structure is made up of simple IPE400 beams and IPE180 beams. On the main structure, IPE180 beams were placed as straps to distribute the loads of the flooring, which is a 10cm layer of concrete and type C connectors every 35cm.

After the recognition of the structural configuration, the parameters that act on the building were determined based on its location, regulations and elements that compose it.

PARAMETERS FOR ANALYSIS

The calculation values of the effects of the actions for the analysis and design of this investigation were obtained from the charges already established in the CTE [8].

Permanent loads

The values prescribed in the CTE-DB-SE were taken for the elements not considered as their own weight in the calculation program.

Own weight	0,35	T/m2
Floor	0,15	T/m2
Finished parts	0,15	T/m2
Installation	0,05	T/m2
TOTAL	**0,70**	**T/m2**

Table 1: Permanent actions.

Usage overloads

The effects of use overload derive from the activity for which it is intended, taking into account that it includes the use of traffic, furniture, belongings, merchandise, machinery, etc. These loads were applied evenly on the pavement. The value of the use overload applied in the analysis was 0.4T/m2, a value used for industrial buildings in the 1970s. This value was used as a constant throughout the area of the building.

Wind

The actions of the wind were not taken into account since, as the CTE says, ordinary buildings are not sensitive to the dynamic effects of the wind.

Thermal actions

The building does not have structural elements greater than 40m in length, so thermal actions that influence its behavior were not considered.

Snow

The snow load used was determined in the CTE for buildings located in climatic zone 4 to which Madrid belongs, in locations that are not strongly exposed. The value of 0.05T/m2 was used.

Earthquake

Arganda is located in the area where the seismic acceleration is less than 0.04g, so compliance with the seismic-resistant construction standard is not mandatory. According to NCSE-02: "In buildings of normal importance with frames well braced to each other in all directions, located in areas with a basic seismic acceleration ab less than 0.08g, the designer can decide to apply the standard".

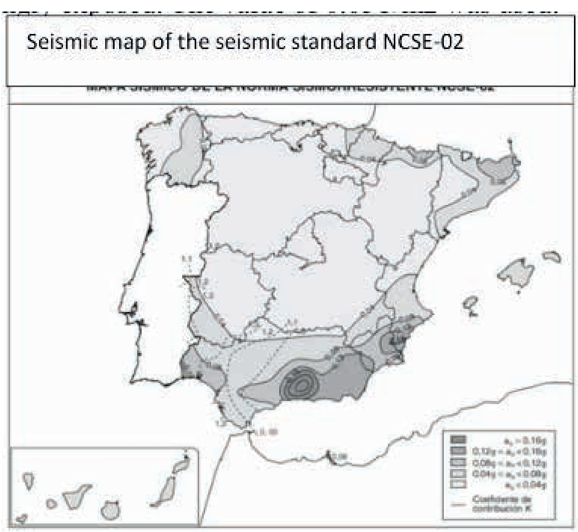

Illustration 3: Seismic map.

STRUCTURAL ANALYSIS OF THE CURRENT STATE OF THE BUILDING

The modeling of the structure was carried out in the SAP2000 program and the structure was analyzed under the aforementioned parameters.

The analysis of the structure [9] indicated that the horizontal elements are working normally within the permissible limits indicated by the CTE code. The results show that most of the beams are working at less than 50% of their capacity, some reaching a maximum of 70% of their capacity [10].

It was observed that some vertical elements exceed their resistant capacity limit but these elements are not part of the proposed system nor do they interfere in the study area of this work, so they were not taken into account. The column axes that enter the study can be observed that they are also working between 50% and 70% of their capacity, so it was considered that the elements do not need any type of reinforcement to consider that it could change the initial approach of the structural reconfiguration.

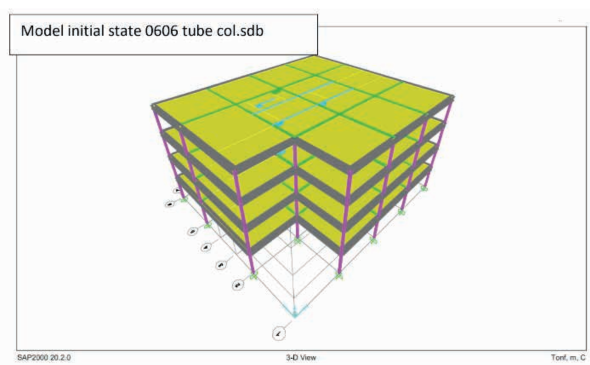

Illustration 4: 3D model of the analysis in the SAP2000 program.

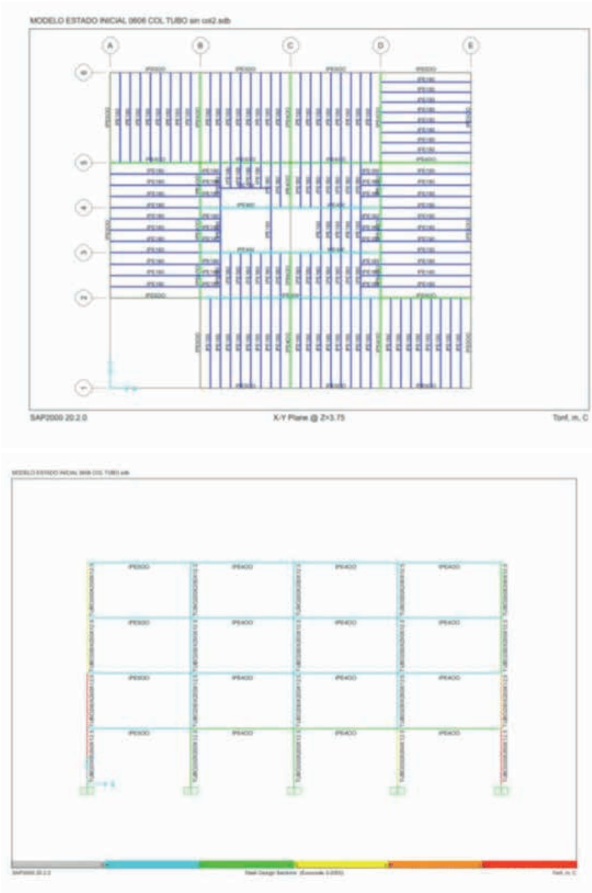

Illustration 5: Original configuration analysis results obtained from the SAP2000 program.

STRUCTURAL ANALYSIS OF THE BUILDING ELIMINATING A COLUMN

With the information already obtained, the column of level N+0.00 of axis C2 was removed from the model, as shown in figure 6. These cases occur when it is desired to reconfigure the spaces in case larger pound spans are needed or in the event that a vertical structural element (column) suffers damage to the point of having to remove the element. This can happen at any level of a building, but in this case the removal of the column that receives all the load from the axis was studied to make it a more critical scenario [11] [12].

For this, a new analysis of the structure was carried out with the new configuration to see how it now acts with these conditions.

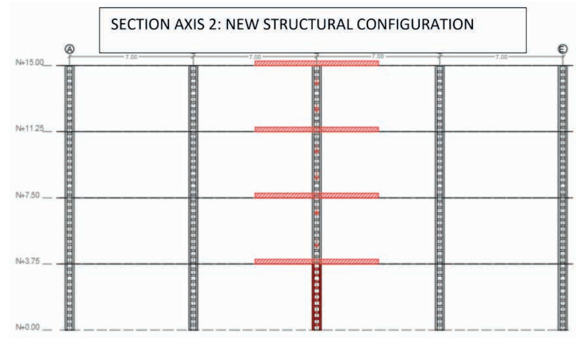

Illustration 6: New building structural configuration.

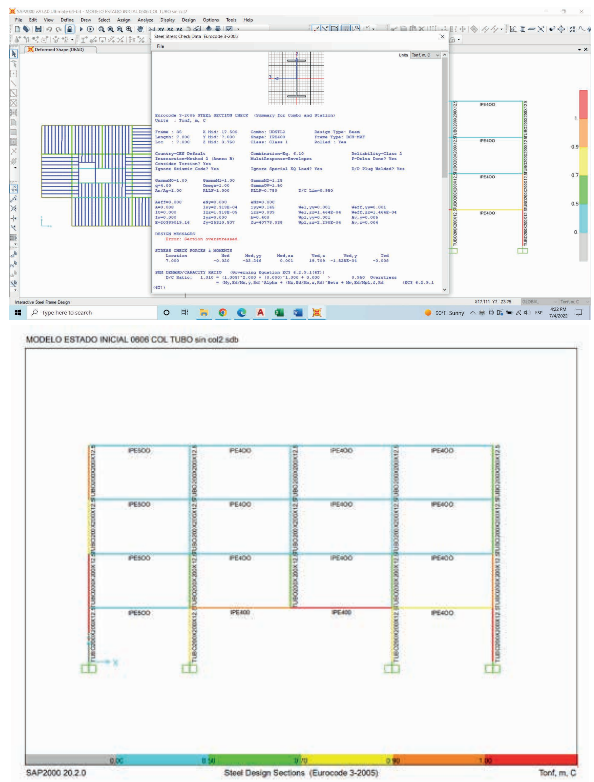

Illustration 7: Analysis report and results obtained from SAP2000.

The results of the new model indicated that beam BC of axis 2 is working at more than 90% of its capacity while beam CD of axis 2 exceeds 100% of its resistant capacity.

With this new analysis, we determined that it is necessary to reinforce these elements so that they support the new load considered from now on as punctual that reaches the node and is transmitted to these elements [13].

It is observed that the joint where the loads are received presents a deformation of 2.8cm greater than the permissible which is 2.3cm, so one of the main objectives is to create a camber that solves this problem [14].

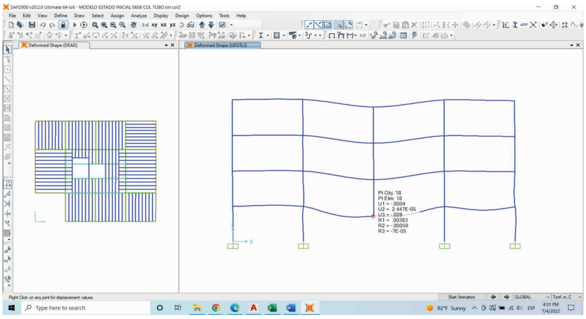

Illustration 8: Deformations of the new configuration.

Structural reinforcement

It was proposed to convert the simple beam into a FINK type beam with an upright in the middle of the span and a prestressing cable that will introduce a force to create a counterspan. With this, it was expected to obtain a direct load reduction on the beam and a decrease in the deflection of the element.

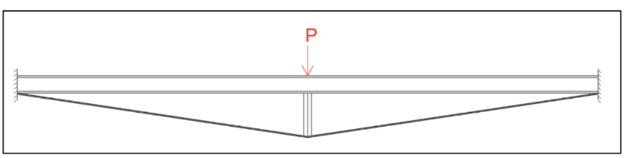

Illustration 9: Fink-type beam reinforcement.

We must understand that a Fink beam is a straight element in which a punctual and permanent central load is applied in the vertical direction through an upright, with the purpose of compressing the main element to improve its resistance to bending when a load is applied to it. positive moment [15].

This beam works well without the need to introduce a prestress, but the reason for this is that when an element is limited to design parameters, the prestressing causes less deformation in the element that could occur [16].

The analysis of the composite structure was given by matrix calculation by the rigidity method.

To analyze the proposed structure, as well as each of its elements, it was necessary to define a coordinate system. In the same way, the possible movements of each one of the nodes of the structure had to be defined.

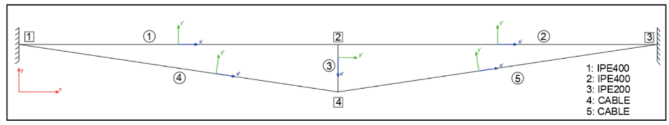

Illustration 10: Coordinates of the reinforcement system.

The stiffness method is based on Hooke's law and its purpose is to obtain the known displacements. Stiffness is the force required to produce a unit displacement in a structure. The matrix approach of the stiffness method is based on the formulation of matrices for each of the members of the structure [17].

The fundamental concept of the stiffness method is as follows.:

$\{F\} = [K] * \{\mu\}$ (1)

Where:

F= Force

K= Hardness

μ= Deformation

To analyze the structure, as well as each of its elements, it is necessary to define a system of coordinates. For the structure it is called the global coordinate system and it is independent, while in the case of individual elements the coordinate system is called local and it depends on the orientation of the elements [18].

Illustration 11: Forces and deformations of the bi-embedded beam.

$$
\begin{vmatrix} X_1 \\ Y_1 \\ M_1 \\ X_2 \\ Y_2 \\ M_2 \end{vmatrix}
=
\begin{vmatrix}
\frac{AE}{L} & 0 & 0 & \frac{-AE}{L} & 0 & 0 \\
0 & \frac{12EI}{L^3} & \frac{6EI}{L^2} & 0 & \frac{-12EI}{L^3} & \frac{6EI}{L^2} \\
0 & \frac{6EI}{L^2} & \frac{4EI}{L} & 0 & \frac{-6EI}{L^2} & \frac{2EI}{L} \\
\frac{-AE}{L} & 0 & 0 & \frac{AE}{L} & 0 & 0 \\
0 & \frac{-12EI}{L^3} & \frac{-6EI}{L^2} & 0 & \frac{12EI}{L^3} & \frac{-6EI}{L^2} \\
0 & \frac{6EI}{L^2} & \frac{2EI}{L} & 0 & \frac{-6EI}{L^2} & \frac{4EI}{L}
\end{vmatrix}
*
\begin{vmatrix} \mu_1 \\ \vartheta_1 \\ \theta_1 \\ \mu_2 \\ \vartheta_2 \\ \theta_2 \end{vmatrix}
$$

To obtain the matrices in the global coordinate system, the transformation matrix is used and a matrix operation is performed.

$[K] = [T]^T * [K'] * [T]$ (2)

Where:

T= Transformation Matrix

STRUCTURAL REINFORCEMENT ANALYSIS

Once the analysis was carried out by means of matrix calculation, the results obtained indicated that in the new system at the critical node there is a deformation of -0.5cm, which is already within the permissible range for the structure. With this we determine that the proposed solution is optimal. The data was entered into the SAP2000 model to determine the new behavior of the structure.

The results indicate that the beams return to work in a permissible range between 70% and 90%, this being optimal for the proper use of the building. The model presents a limitation in the amount but it is due to conflicts of the SAP2000 program with the compact elements that is the case of this element due to its short length, however the piece complies with the resistance and behavior necessary for the reinforcement.

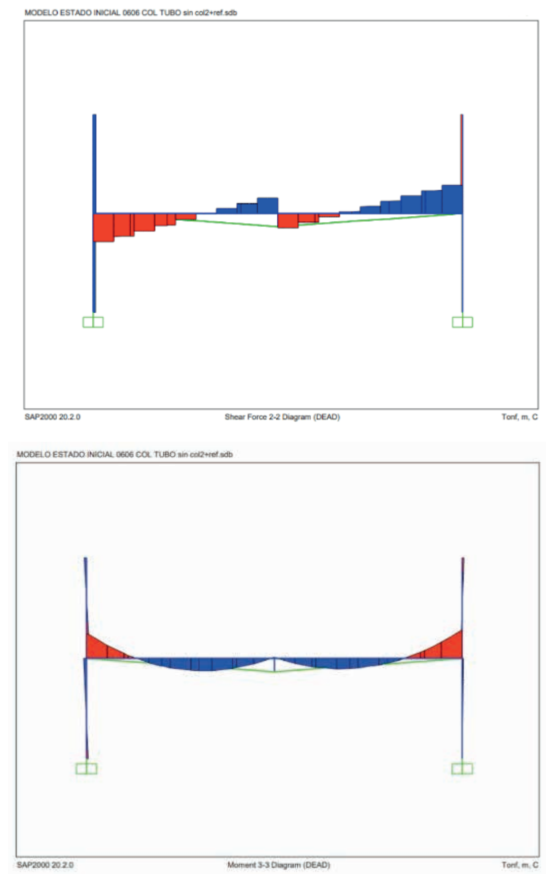

Illustration 13: Shear and moment diagram.

REINFORCEMENT DESIGN

The reinforcement system is made up of the two 7m long IPE400 beams which, as the analysis indicates, meet the required stresses; these are joined in the center with a plate and bolts. At this point, a 50cm long IPE200 vertical beam is placed on top. A guide is placed for the prestress cable that will give stability and shape to the path that it must take. Active-active type anchors are placed at the ends, that is, both sides of the cable will be tensioned. The force to be introduced will be 12T, which is the resistant standardized force of the 7-strand cable selected for the reinforcement [19-21].

For the analysis of elements such as bolts and plate, the guidelines of the ACI (American Concrete Institute) code were used, where creep, rupture and shear block resistance are verified [22].

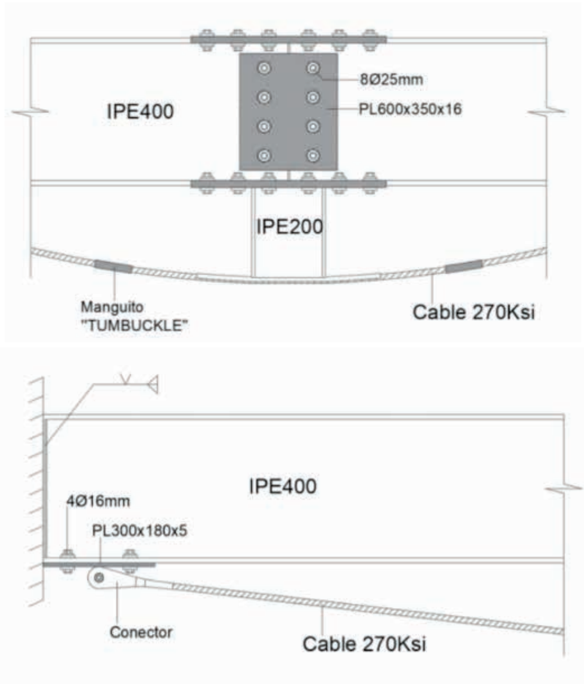

Illustration 14: Design of post-tensioned reinforcement elements.

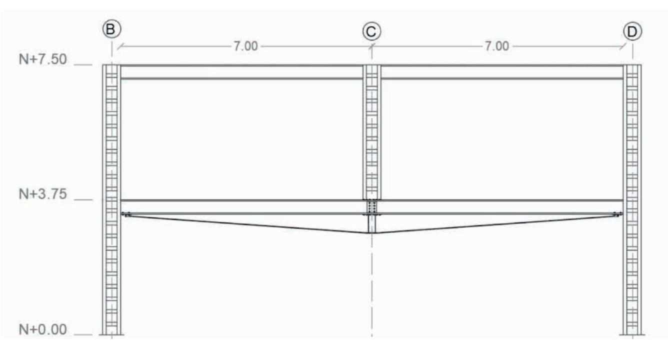

Illustration 15: Sectional view of the post-tensioning reinforcement in the frame.

CONCLUSIONS

- Once the study of active reinforcement in metallic structures has been carried out, it is noted that the little use of this system is due to the fact that the structural performance of steel is optimal in traction, while the prestressing has been characterized as a reinforcement that introduces a force of Compression and the naked eye must not be compatible, but when it is applied within parameters that allow the materials to act according to their own nature, a system that presents structural benefits is obtained.

- To study the history of the development of prestressing, we can determine that it has evolved mainly to solve elements where large spans or large pieces are required, since traditional methods such as reinforced concrete do not work well under these requirements.

- It is determined that the use of FINK type beams are a positive solution for the reinforcement of metallic structures since the system presented advantages of simplification of calculation, it adapts to the application spaces since it is not an invasive system that requires additional configurations in the environment, as it requires few elements, this system is cheaper than a passive reinforcement and, in turn, the execution time is less. This meets the stated objective of developing a more environmentally friendly intervention, this is due to the fact that it was possible to provide a solution to be able to extend the life time of a structure under new structural safety parameters.

- Based on the analysis and the theory studied, it is said that the use of a prestressed reinforcing frame in elements of metallic structures is applied to control or recover permissible deformations according to the structural technical code. Thus, this reinforcement can also be applied in order to change the way the elements work to create a redistribution of efforts.

- It is important to mention that the prestressing of metal structures must not be applied with the intention of introducing significant shear forces, since we would be subjecting the elements to work against their optimal behavior.

- To carry out the initial analysis of the structure of Lácteos de Arganda, we obtain results in which it is possible to appreciate the good structural performance over time since its main elements did not present greater overstress according to the results.

- We determined that with the application of active reinforcement in the structure of Lácteos de Arganda, a configuration of spaces can be made that allows the building to be given a new use under different needs than those for which the building was conceived.

- It is necessary to clarify that the active reinforcement of prestressing does not cause an increase in the resistance of the elements in which it is applied, what the reinforcement does is a redistribution of efforts and the introduction of a tension that acts on the deformations of the elements. items.

- Finally, we conclude that the reinforcement of the structure of Lácteos de Arganda is possible due to the good use and maintenance that it has received over time, since in order to reinforce a structure, it must have minimum conditions of resistance and capacity.

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