Criterios para el refuerzo de estructuras metálicas: Rehabilitación del “Círculo de Bellas Artes” y la “Casa Encendida”

Criteria for steel structures reinforcement: Restoration of the “Círculo de Bellas Artes” building and the Cultural Center “Casa Encendida”

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Resumen

Este trabajo resume unos criterios fundamentales para el diagnóstico y la posterior rehabilitación de las estructuras de acero. La adaptación de los edificios a los nuevos usos demandados por la sociedad junto con la creciente preocupación por la conservación del Patrimonio Arquitectónico, implican la necesidad de revisar los procedimientos tradicionales en la intervención y conservación de las construcciones históricas. Entre las posibles líneas de actuación, este trabajo se centra en las ventajas de la rehabilitación de las estructuras metálicas mediante su transformación en estructuras mixtas. Junto con las ventajas derivadas del comportamiento mecánico como sección mixta, hay que añadir el reducido coste y la mejora de numerosos aspectos como pueden ser el aislamiento acústico, térmico, etc. En este trabajo se presentan los trabajos de rehabilitación llevados a cabo en dos edificios emblemáticos de la capital: el edificio del Círculo de Bellas Artes y el Centro Cultural “La Casa Encendida”.

Palabras claves: Diagnóstico, rehabilitación, estructuras metálicas, sección mixta, patrimonio arquitectónico

Abstract

This paper introduces the fundamental criteria for the diagnosis and restoration of steel structures. The adaptation of buildings for new uses not considered in their origins and the increasing interest in the correct conservation of the Architectural Heritage, have promoted the update of the traditional techniques typically applied in restoration of historical constructions. Among a large number of possibilities, the present work is focused on the advantages of restoration by means of turning steel structures into concrete-steel composite structures. This technique provides a large array of advantages: mechanical behavior of concrete-steel composite beams, low cost of repair and improvement of several factors, such as soundproofing and thermal insulation. Furthermore, this paper includes the repair procedure for two emblematic buildings of the Architectural Heritage in Madrid: the “Círculo de Bellas Artes” and “La Casa Encendida”.

Keywords: Diagnosis, restoration, steel structures, concrete-steel composite beam, architectural heritage

1. Introduction

The society is increasingly demanding for higher architectural quality, which leads us to continuously review the accepted standards to update old-historical constructive typologies. However, this continuous demand comes into conflict with some other parallel objectives: preservation and restoration of historical buildings. There is a feature in each society, which represents its culture, past activity and, therefore, its own future expectations.

A large part of the Historical Architectonic Heritage buildings were constructed by using steel structures, in the specific construction field, by employing slabs solutions and different kinds of metal beams. Such historical buildings were built in accordance with the inherent possibilities granted by this new material at that time. These building have remained and will continue to do so in the future, mainly because of their adaptation ability to new purposes, which are different to those they were originally designed for.

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Architectonic Heritage buildings constructed with steel structures can be regarded as the result of metallurgical advances over the past two centuries, accompanied by the theoretical-experimental knowledge acquired on the mechanical behavior of metal structures. Besides, it is worthwhile mentioning the creativity of new types of structures as well as the development of new constructive technologies. The historical process of steel building can be considered as the result of an extraordinary endeavor to learn the lessons from impressive failures - overcame failures already - although some of them are quite recent. For example collapses produced by buckling effect taking place between 1969 and 1971 in Vienna, Gales, Melbourne and Coblenza.

2. Discussion and development: criteria used to restore metal structures

It is important to make clear that in new building projects, there are not external restraining criteria that limit technical solutions to be employed when dealing with a problem. However, in restoration projects, there are many limitations. When restoring historical buildings, built under past techniques, which were incipient in many aspects, many problems have arisen. Such is the case of steel. Previous considerations on steel are introduced in the first place.

2.1 Base material and welding

The material traditionally known as "steel" had not always achieved an adequate quality to be properly considered as steel, even in relatively recent years. Therefore, during the data collection phase of any restoration project, for an old metal structure, samples shall be taken to carry out the traditional tensile strength test, a resilience test and a chemical composition analysis. Resilience analyses results enable the evaluation of weak cracking sensitivity indirectly affecting the material weldability. With the results obtained from chemical analysis, steel components percentages can be compared (carbon, phosphorus, sulfur, silicon and magnesium) to the standards provided by the regulation (revoked) NBE-EA-95 (NBE-EA-95,1996), summarized on Table 1.

Tabla 1. Límites normativos de los distintos componentes del acero
Table 1. Regulated limits of several steel components

COMPOSICIÓN QUÍMICA DE ACEROS SOLDABLES/ CHEMICAL COMPOSITION OF WELDABLE STEELS	
C	£ 0.19 % - 0.27 % según calidades y espesores/ as per quality and thickness
P	£ 0.050 % - 0.060 % según calidades/ as per quality
S	£ 0.050 % - 0.060 % según calidades/ as per quality
N	£ 0.010 %
Si	£ 0.55 % para aceros A52/ for steels A52
Mn	£ 1.60 % para aceros A52/ for steels A52

Chemical compositions summarized on Table 1 are essential for the hypothetical use of regular welding procedures. Building Technical Code (CTE. DB-SE-A., 2006) restricts thicknesses in function of resilience (in function of qualities JR, J0 and J2) and it indicates the allowed limit for weldability C_{EV} according to (NBE-EA-95,1996), with a maximum of 0.41 for steels S-235 and S-275 and; a maximum of 0.47 for steels S-355.

$$C_{EV} = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15} \quad (1)$$

The potential "sheet defect" shall be taken into account in restorations works with old metallic structures, where the material is determined as a weldable material (even more when the material is not considered so) and also for current structures. This is a quite frequent situation suffered by steels, which refining methods were carried out by means of procedures already disregarded.

Figures 1 and 2 show how polluted particles were not homogeneously distributed in the material. On the contrary, they tended to locate on determined planes. Consequently, the design criterion for the restoration of metallic structures indicates that tensile strength shall never be applied in perpendicular direction to the metal-forming plane. Therefore, special attention shall be granted to flexure points, especially those of an isostatic nature. Figure 1 shows how problematic the reinforcement on defective pieces can be. Even in cases where abovementioned criterion is respected.

Figura 1. Zonas de posible acumulación de impurezas en la laminación
Figure 1. Potential zone where polluted particles might be accumulated in metal forming plane

Figure 2 shows a proper criterion design for welded metal joints, which consists of transforming tensed joints into joints assembled by grade beams. Besides, it is important to carry out non destructive tests, thus contributing with valuable information to assess the reinforcements in existing metal structures; no matter they are new or old ones.

Figura 2. Detalles de uniones metálicas soldadas
Figure 2. Details of welded metal joints

2.2 Reinforcement of a steel structure

This paper presents some key criteria for the diagnosis and later restoration of steel structures to be preserved as essential component of a building.

Firstly, in most cases where an Architectonic Heritage structure is restored, it is not possible to meet the requirements established by the current regulation (NBE-EA-95,1996; EHE-08, 2008; UNE-EN-1993-1-1, 2008; UNE-EN-1994-1-1, 2011) without demolishing the building. Demolition will lead to the replacement of heritage within a relatively short time, inevitably losing our history, and not considering the high costs involved.

Among the potential measurements, this job is focused on the restoration of metal structures by means of their transformation into concrete steel composite structures. In steel-concrete sections, the metal profile mainly works under tensile strength, receiving loads derived from flexure stresses. On the contrary, concrete works under compression, thus showing a better behavior, by also increasing stiffness and the mass of the composite slab. Therefore, in addition to the advantages derived from the mechanical behavior of concrete steel composite structure, several advantages provided as soundproofing and thermal isolation shall be considered, because they are hardly achieved by other means.

By employing concrete-steel composite beams, several issues are simultaneously solved. The main parameters modified by this type of intervention, which are required for the restoration of existing structures, are introduced below.

2.2.1 Deformation Control

Metal structures were normally dimensioned according to resistance criteria, leaving aside stiffness conditions. Once a building restoration is proposed, the purpose of this building usually changes. The elements supported by slabs, such as floor plan and partitions, will also be modified.

In such cases, it is expected that problems derived from the excessive deformability of the current metal slab will take place.

2.2.2 Vibration Control

Nowadays, many interventions imply significant usage changes. Thus, many heritage buildings are restored to be used as public service facilities visited by a huge amount of users, such as cultural centers, exhibition halls, etc. For this type of buildings, vibration behavior (ACHE, 2001) can be decisive to design the type of slab to be constructed.

2.2.3 Increasing supporting capacity

It is quite common that usage changes lead to the need of providing higher supporting capacity to the original structure, either direct (e.g. greater load derived from a larger foot plan due to new usage) or indirect (e.g. requiring a slab/extension on decks to host new facilities meeting the requirements of the new usage).

2.3 concrete-steel composite beams

Traditional steel construction commonly used for historical buildings is based on double T metal profiles. In many cases this type of slab lacks of a compression layer, which lead to structural problems, such as: partial cracking of the beam layout. Furthermore, it is normal that surface finishing may have a high constructive interest, such as frescoes on roofs, the presence of high quality plaster works, etc. It is worthwhile mentioning that the criterion to be applied on restoration of Historical Heritage buildings is to preserve the architectonical quality as much as possible.

Building a concrete-steel composite beam, from a metallic structure, only requires the elaboration of a concrete block compatible with the metal profiles to be reinforced. This reinforcement criterion uses the existing structure to create a new compression layer on the whole slab, which is capable of definitively solving the typical weakness problem provoked by the traditional beam layout.

The transformation of a metal structure into a concrete-steel composite structure, by means of supporting a new concrete block with existing metal profiles, can be done in different ways:

- **Slab-embedded head caps:** *It consists of a solution provided to connect both, concrete and steel perimeters.*
- **Head caps built on the profiles:** *This solution considerably increases the final edge of metal structure. The connection system is achieved by using connectors mainly. Presently, there is a huge amount of connectors' types, which are compatible with the existing steel profiles. They can be welded (when steel is suitable for this purpose) or they can be fixed by using mechanical end plates. Some potential examples are shown on Figure 3.*

Figura 3. Ejemplo de conectadores
Figure 3. Examples of connectors

Regarding the type of concrete to be used, there is also a wide variety of options. Some of them correspond to the several performances provided by this material: from lightweight structural concrete, which reduces the loss of ultimate loading capacity, due to a higher control of its own weight; up to high strength concretes capable of reducing the volume to be used; besides they reduce the task execution period. It is worthwhile mentioning that a concrete slab can be used as surface finishing, by employing surface treatments (continuous concrete blinding floor, colored concrete, etc.). Furthermore, concrete performance as fire insulating system shall also be taken into account.

2.3.1 Advantages over the vibration behavior of metal structures

The research on this kind of structures regarding Vibration Ultimate Limit State is quite relevant, although it is commonly not assessed. This analysis is important in many historical heritage buildings restoration, because such architectural monuments are generally used as public service facilities, such as cultural centers, exhibition halls, conference rooms, etc.

The traditional metal structure reinforcement, which increases the static stiffness, in many cases is not enough to solve vibrations problems. On the contrary, the transformation into a concrete-steel composite structure is generally enough to meet an adequate vibration behavior (S.J. Hicks, J. Brozzetti, B. Rémy y R.M. Lawson, 2003).

The restoration examples included in this research job include specific cases of interventions on existing structures of Architectonic Historical Heritage buildings, which introduce criteria and the parameters employed, as well as obtained results.

3. Analysis criteria for reinforced beams

In the first place, we shall begin analyzing the metal structure intervention, by assuming the presence of "residual stresses" derived from the constructive process. We must be aware of these stresses, before applying external loads, which is not an exclusive condition related to welded structures.

As examples, we may highlight the commercial brand profiles, which generally have different degrees of residual stresses, as the result of their laminating process.

From a rigorous theoretical approach on the elastic calculation, we could wrongly conclude that internal stresses are void, in case loads are not present. If residual stresses can be ignored by elastic calculations, it is precisely because high quality steel elements (properly designed) have an adequate plastic behavior. Besides, the steel elements have also met regulated standards, such as bracing limitations and local/general slenderness restrictions.

By making an explicit record of above conditions, in principle, there should be no restrictions against the essential plastic calculation methods, especially for the enhancement of reinforced pieces, as depicted on Figure 4.

Figura 4. Ejemplo de gráficas tensión-deformación en el refuerzo de vigas
Figure 4. Examples of stress-strain curve of beams reinforcement

This example shows that the starting point of a tensile stress curve for a reinforced beam is quite irrelevant, provided that the tensile stress plastic distribution is achieved in the ultimate limit state. However, the elastic calculation of this solution would be completely conditioned by the existence of initial tensile stresses and by the subsequent early plastification at some reinforced section point. Only employing the plastic calculation method, the “actual” increase of the beam loading capacity can be explained, thus allowing the increase of service overloading.

By transforming the metal structure into a concrete-steel composite structure, it is possible to obtain a similar or maybe a higher performance from the beam employed in the example on Figure 4. This procedure is explained in the following actual restoration cases, which are enhanced by using the sectional plastic calculations.

4. Restoration examples of historical heritage buildings.

4.1 Fine Arts Circle building in Madrid

The fine Arts Circle building is located at the Alcala Street, next to Spain Bank in Madrid. This building was constructed in 1921, by the architect Antonio Palacios. It has an eclectic style and it was appointed as an Architectonic Historical Heritage building and also declared as Cultural Heritage Center.

This paper summarizes the restoration works developed in two rooms: The Columns Hall and the Library Records Office.

4.1.1 Columns Hall

In the original project, this room corresponded to the Casino Playroom. Currently this room is employed as a multiuse room where concert, conferences and experimental theater plays are held. The Fernando Rojas Room is located underneath this room, which was originally used as Lecture Room. Nowadays it is restored and employed as a theater.

Figura 5. Fotografía de la Sala de las Columnas
Figure 5. Picture of Columns Hall

The existing structure is made up of a slab covered with a metal structure, which is composed of two sets of main beams, which support a uni-directional slab. The slab, shown on the Figure 5 and drawing on Figure 6, is made up of IPN-type joists with 80 cm spacing between the beams. It also has an arc between steel beams on a brick deck filled with gypsum. There is no compression layer on the deck, so the floor is directly laid on it.

The slab is supported by a primary set of beams made of solid webbed laminated profile of 40-cm edge and 10 meter span, which is supported by reinforced beams made of covered plates and angular rivets, with edges ranging from 100 up to 120 cm. Beams support spans ranging from 11 up to 13 meters, directly supported by the structure columns. Columns are constructed by pairs of UPN type profiles fastened one to each other.

All joints, conceptually compatible, were made by using rivets. The structure covers a diaphanous space between columns of 13x13m, as shown on Figure 6.

Figura 6. Planta de la Sala de las columnas
Figure 6 Floor on Columns Hall

The purpose of the intervention task on the Columns Hall is explained by disturbing vibrations taking place in the room floor, so the task was focused on the slab reinforcement. These vibrations mainly took place in the room without affixed chairs, while there was a huge amount of attendees, specifically in the room central point. The vibrations clearly affected the adequate activity performance.

Apart from these slab vibrations, there were also functionality problems in the Fernando Rojas Room, underneath Columns Hall, because illumination devices hanging from the ceiling were also affected by movements, thus requiring the adjustment of spotlights positions. The highest point of this room is completed with a plaster molding annular vault, hanging from the Columns Hall slab. The annular vault is decorated with golden leaves, which naturally avoid any intervention to the slab lower part. Furthermore, some illumination devices are also hanging from the ceiling. Besides, there was a poor soundproofing system between both rooms. Therefore, they could not be used at the same time.

Consequently, restoration task was focused on the slab upper side, thus avoiding damaging the annular vault elements.

Firstly, data kept from the original project were studied in order to diagnose the existing slab. Afterwards a static analysis was performed so as to check the slab safety, which yielded allowable safety coefficients for all slab components. The maximum values from static arrows under ultimate limit states were also checked, which results were somehow high. However, they could be considered allowable values because there were no partitions or damageable elements.

Finally, the main elements were studied under dynamic action state, thus finding their frequency values, as well as acceleration and oscillation amplitude values. In some cases, the values obtained exceeded the recommended allowable limits for this type of structure. These results correspond to disturbing vibrations taking place in the slab, mainly during dynamic activity performances held in this room, such as dance ballroom, parties, meetings, etc.

Criteria to be employed to restore the slab were analytically obtained by following parameters and the function of the problem to deal with. The purposes determined, regarding excessive strain, are summarized as follows:

- Increase of the structure static stiffness, so that the existing beams are able to work as concrete-steel composite structure.
- Addition of concrete on mixed caps, thus increasing damping effect on the composite structure.
- Increase of dead loads (own weight and floor plan), thus improving the relation between overloads and the permanent slab load.

According to the results of this study and taking into account the impossibility to work on the slab lower side, the restoration tasks were determined, thus reinforcing different slab structural elements. On one hand, a compression layer of 4-5 cm was laid on the whole slab structure, with the corresponding reinforcement mat.

On the other hand, main slabs were reinforced by using compression head caps of 100 cm width and 18 cm thickness, which are embedded in the slab covering the existing profile upper wing. Connection between concrete and steel is achieved by welding a frame to the profile upper wing. The profile surface is covered with concrete, thus bonding concrete and steel.

Figura 7. Secciones de las vigas mixtas
Figure 7. Sections of concrete-steel composite slabs

The proposed restoration work, shown on Figure 7, was developed under the following construction process considering the peculiar existing conditions of the intervention.

- Demolishing the existing pavement and the surface cover layer, until finding the steel profile upper face.
- Demolishing the ceramic spacing formed by bricks, so as to later place reinforced concrete head caps on the composite section.
- Setting a steel formwork to create a steel-concrete composite structure with head caps, which are then sealed during the concrete cast-in phase.
- Cleaning profile upper wing to ensure the adequate bonding between concrete and profile, thus securing the composite structure performance.
- Setting the reinforcing steel by welding steel frames with connection caps to the profile upper wing.
- Covering the surface with epoxy-resins to increase concrete-steel bonding.
- Concrete casting using a HA-25 pump with 15 mm aggregates.

Chemical analyses were carried out to check the existing steel weldability. Although acceptable results were obtained, the additional intervention of concrete-steel bonding connection was restricted to the compressed profiles upper wing.

The intervention results show that natural frequency values were hardly improved, due to the increase of the structure static stiffness and the unavoidable increase of the slab mass. However, this intervention solved the problem related to other parameters involved in the vibrations ultimate state, such as acceleration and oscillation amplitude. Consequently, the obtained values were reduced by half regarding the original ones. Additionally, there is an improvement of the damping effect in the structure, which is not directly reflected by calculated values.

4.1.2 Library Records Office

The intervention area corresponds to the floor mezzanine slab located underneath the Library. Similarly to above case, the slab lower face is part of an important ceiling decoration formed by plaster molding and paintings. Such ceiling corresponds to the Dance Ballroom; therefore, it is not possible to restore the slab from its lower face without damaging the existing decoration.

The original structure is made of a unidirectional isostatic slab, with 9 m span, constructed with IPN-240 profiles. Spacing between center lines of the beam is of 80 cm, covered with ceramic bricks filled with gypsum. As it was traditional in slabs constructed at that time, there is no compression layer at all; therefore, the floor is directly laid on the slab. Therefore, if the floor is removed, the profile upper wing will be uncovered thus allowing restoration works.

The existing slab does not show excessive strain or vibration problems, due to the static nature of overloading derived from the room usage as storehouse and library records office. The intervention is carried out to increase the slab resistance capacity. The restoration plan considers the installation of compact file cabinets, thus overloading the structure far beyond its initial design. Provided that there is a relatively small storey height (2.20 m), it is estimated that installing compact file cabinets will involve a maximum overload of 8 kN/m² approximately.

According to original data and to the restoration purposes, the plan is to reinforce the slab with an adequate framework to endure the new load. Strains were limited to allowable values, so as to ensure that lower decoration was not damaged.

Figura 8. Sección del refuerzo

Figure 8. Reinforcement section

In order to carry out the planned restoration task, shown on Figure 8, a 10 cm-compression layer was laid on the whole slab surface, which is connected to the slab upper wing, thus forming a composite structure. Since it is not possible to brace the slab during construction, it was decided to execute the compression layer using a lightweight concrete, so as to reduce slab strains during concrete cast-in phase. During the construction process, it is not possible to calculate the resulting stiffness of composite structure. However, the weight of concrete shall be considered.

Figura 9. Fotografía de la obra antes del hormigonado

Figure 9. Picture of the intervention before concrete cast-in

For the development of a new compression layer, a concrete with 1550 kg/m^3 density was employed, which has a minimum characteristic strength of 20 N/mm^2 . Because of the reduced area involved in this intervention (some 400 m^2), "Hilti" type connectors were nailed to the structure, thus avoiding welding them, as shown on Figures 8 and 9.

Once reinforcement was carried out and the slab was loaded according to the new layout, a proper mechanic behavior was demonstrated.

4.2. Cultural Center "La Casa Encendida"

The Cultural Center "La Casa Encendida" is located at number 2 Ronda de Valencia Street, Madrid. It was constructed by the architect Fernando Arbós. It corresponds to the Neo-Mudejar style and it is a building protected and characterized as Historical Heritage Building of Madrid Community.

The restoration carried out consists of intervening the slab frame, which has a total surface of 4500 m^2 distributed in several floor plans.

The original structure is composed of unidirectional isostatic slabs, with 9 m spans, constructed with IPN-240 profiles, supported by brick masonry load-bearing walls. Spacing between center lines of the beam is 80 cm app., which is supported with ceramic bricks covered with gypsum in situ. According to traditional practices for slabs constructed at that time, there is no compression layer and the floor is directly laid on the slab. Similarly to the above restoration, if the floor is removed, then the profile upper wing is discovered and the intervention is ready to be effected.

In this case, the restoration purpose is to modify the original slab for new purposes, such as exhibition hall, conference room, offices, etc. Consequently, the existing slab was not suitable mainly because of its ultimate service state and, it requires a reinforcement restoration.

The restoration consisted of reinforcing the slab by laying a continuous compression layer of 10 cm. In this case, it was decided to use a regular concrete type HA-30 because bracing the slab during the execution phase was possible. Figure 10 shows a picture of the intervention process before concrete compression layer cast-in

Figura 10. Fotografía de la obra antes del hormigonado

Figure 10. Picture of the works before concrete cast-in

The connection between the profile and concrete, in the composite structure, was developed by using connection bolts type Köco. Their arrangement was performed in accordance with the manufacturer specifications by using a semi-automatic welder machine. Figure 11 shows developed reinforcement specifications. Figure 12 shows the bolts already connected, but still bearing their protective ceramic bands.

Figura 11. Sección del refuerzo realizado
Figure 11. Section of developed reinforcement

Figura 12. Fotografía de obra
Figure 12. Picture of the work

In order to ensure the process validity and to guarantee the existing profile weldability, laboratory tests were performed on the welding connection. For such purposes, a sample of the existing profiles was extracted. Connecting bolts were welded to such samples and then they were tested under tensile strength. The results were adequate for all cases, thus ensuring the quality of bolt welding. Therefore, the connection between the concrete compression layer and the existing metal profiles is also adequate. Table 2 and Figure 13 show a summary of the most significant data of the executed reinforcement.

Tabla 2. Resumen de datos del refuerzo
Table 2. Summary of Reinforcement Values

CARGAS CONSIDERADAS/ LOADS CONSIDERED	ESTADO ACTUAL (Sección Metálica)/ EXISTING CONDITION (Metal structure)	ESTADO REFORZADO (Sección Mixta)/ REINFORCED CONDITION (Composite structure)
Forjado (doble tablero de rasilla)/ Slab (double deck and bricks)	2.0 kN/m ²	2.0 kN/m ²
Capa de compresión (4 cm)/ Compression layer (4 cm)	1.0 kN/m ²	
Losa de refuerzo de hormigón (HA-30, 10 cm)/ Concrete reinforced slab (HA-30, 10 cm)		2.5 kN/m ²
Solado continuo (2 cm)/ Continuous floor (2 cm)	0.5 kN/m ²	0.5 kN/m ²
Sobrecarga uso/ Overloading	5.0 kN/m ²	5.0 kN/m ²
Carga Total/ Total load	8.5 kN/m ²	10 kN/m ²
COMPROBACIONES NUMÉRICAS/ NUMERICAL VERIFICATION		
RESISTENCIA/ RESISTENCE		
Momento flector máximo/ Maximum flexural moment	60.0 mkN	70.9 mkN
Tensión fibra superior: compresión/ Upper fiber tensile stress: compression	-170 N/mm ²	-23.0 / -5.4 N/mm ²
Tensión fibra inferior: tracción/ Lower fiber tensile stress: tensile stress	+170 N/mm ²	+130 N/mm ²
Coefficiente de seguridad (elástico / plástico)/ Safety coefficient (elastic/plastic)	1.41 / 1.64	1.86 / 2.40
DEFORMACIÓN/ STRAIN		
Inercia (instantánea / final)/ Inertia (instant/ final)	4250 / 4250 cm ⁴	14248 / 11212 cm ⁴
Flecha final (a plazo infinito)/ Final arrow (Infinite term)	57.0 mm	25.4 mm
Flecha activa/ Active arrow	33.5 mm	14 mm
Flecha instantánea por sobrecarga de uso/ Instant arrow due to overloading	33.5 mm	10 mm
VIBRACIONES/ VIBRATIONS		
Frecuencia propia/ Natural frequency	2.90 Hz	4.70 Hz

Figura 13. Esquema en sección del refuerzo realizado
Figure 13. Drawing of reinforcement

5. Conclusions

The two examples of restoration on Architectonic Historical Heritage buildings, introduced by this research job, clearly show the advantages of reinforcing a metal structure by transforming it into a concrete-steel composite structure. By employing this intervention procedure, not only the increase of mechanic characteristics of the supporting section is easily achieved. It also influences the enhancement of other parameters that improve the global behavior of the structure, thus exceeding the results of other potential reinforcement alternatives.

The most outstanding advantages of this method are summarized as follows:

- *Reinforcing the structure without demolishing its main elements.*
- *Increasing static capacity, thus leading to higher resistance capacity and stiffness.*
- *Increasing the structure natural frequency, thus resulting into better behavior towards vibrations.*
- *Employing a material (concrete) with adequate structural behavior when faced to damping conditions, thus leading to an improved dynamic response.*

Increasing the slab mass, thus indirectly increasing comfort conditions, improving thermal inertia and providing higher soundproof isolation.

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