PRINCIPLES OF COMPOSITE CONSTRUCTION APPLIED TO STRUCTURAL REHABILITATION OF HISTORICAL CENTRES

Abel Pérez Zuniga

ABSTRACT

This paper presents a solution for the reinforcement of metallic profiles and slab frames, using the principles of the composite construction. The model increases the stiffness and strength of the composite section without increasing the loads due to the use of expanded polystyrene elements. Added concrete and the existing profiles are joined through the adherence in the contact surface between both materials; consequently, it is not necessary the use of expansion bolts as shear connectors.

A case study is presented: the rehabilitation of an existing building in the Historical Centre of Havana. The procedure applied included different non-destructive tests, in order to estimate the residual resistance of the damaged structure. A quality control was applied in order to assure the correct implementation of the model. An economic evaluation of the proposed solution is also presented.

The principles of calculus and diagnosis methodology can be used in more than 500 buildings, erected in the latest decade of 19th century and the beginning on 20th in the Historic Centre of Havana. Most of these constructions are housing buildings, which supposes a highly social impact and benefit of life quality and also a positive effect in urban environment.

The rational use of the materials and resources makes possible the generalisation of these solutions to other historic centres; taking into consideration each particular case, the damage level and the future use of the buildings; allowing the optimisation of future rehabilitation projects and economical savings.

Keywords: Rehabilitation, Reinforcement, Composite construction, Historic Centre

1. INTRODUCTION

The Historical Centre of Havana has an extension of 2.14 km² and more of 3000 buildings. Its restoration is being carried out by city's Historian Office.

The structural typology of frames made of metallic profiles (and concrete or ceramic slabs) is wide spread in the Historic Centre of Havana. It has been used in more than 570 buildings of different architectural styles, most of them housing buildings.

The majority of these edifications present a high degree of deterioration, in which the horizontal structure is the most damaged element. Main causes are the overcharges, incorrect interventions and lack of maintenance. There are also several damages caused by a lack of periodical maintenance: differential deflection and corrosion on the profiles, partial or complete rupture in slabs, etc.

The combination of two or more materials in a unique structural section is called composite construction. This is a general concept applied to new constructions as well as to rehabilitation of buildings. There are different possible combinations: concrete-steel, concrete-wood, steel-wood, etc.

This paper presents a solution for the reinforcement of metallic profiles and slab frames, using the principles of the composite construction. A case study is presented: the rehabilitation of an existing building in the Historical Centre of Havana.

1 Civil Engineer, Master in Sciences, GDTM inc. – CEGEP Trois Rivières, abelpzuniga@gmail.com
2. FRAMES MADE OF METALLIC PROFILES AND CONCRETE OR CERAMIC SLABS IN THE HISTORICAL CENTRE OF HAVANA

This system was used in housing and commercial buildings, with maximal charges of 25 kN/m². There are 571 buildings with this type of structure, the 21.56 percent of the total in the historical centre [1]. The proportion of this system according to each sector of the historical centre is shown in the following table:

<table>
<thead>
<tr>
<th>Historical Centre Sectors</th>
<th>Reported buildings</th>
<th>Buildings presenting the studied system</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prado</td>
<td>114</td>
<td>12</td>
<td>10.53 %</td>
</tr>
<tr>
<td>Catedral</td>
<td>687</td>
<td>158</td>
<td>23.00 %</td>
</tr>
<tr>
<td>Plaza Vieja</td>
<td>647</td>
<td>149</td>
<td>23.00 %</td>
</tr>
<tr>
<td>Belén</td>
<td>567</td>
<td>127</td>
<td>22.40 %</td>
</tr>
<tr>
<td>San Isidro</td>
<td>634</td>
<td>125</td>
<td>19.72 %</td>
</tr>
<tr>
<td>Total</td>
<td>2649</td>
<td>571</td>
<td>21.56 %</td>
</tr>
</tbody>
</table>

There are three different typologies, according to the component elements:
- Metallic profiles and ceramic curved slabs.
- Metallic profiles and solid concrete slabs.
- Metallic profiles and lighten concrete slabs.

These examples are shown in the following images:

Some of the damages observed in these typologies are due to its conception, which did not suppose a different structural concept taking as reference the wood frames used in 19th century. The metallic profiles are the main supporting elements, and there is not a rigid superior frame to achieve the load distribution. Due to this conception, the system presents deficiencies in flexion, due to the vibrations caused by the variable overcharges [2].

Another deficiency is observed: the majority of these buildings do not have a concrete element supporting the frames, so the profiles are supported directly by the walls. These walls were often made of earth, stones or ceramic bricks, presenting fissures due to the point loads. Additionally, the lack of a maintenance policy and the inadequate exploitation has provoked different levels of damage in these buildings [3]. Weather conditions through more than a century has to be considered too.
3. THE PROPOSED COMPOSITE SOLUTION

There are not official standards in Cuba to calculate composite structures in the rehabilitation of buildings. Standard NR 080:2004 [4], conceived only for new constructions, has been taken as reference. This research proposes some modifications, taking into account the loss of transversal section in damaged profiles, and a different way of union; considering adherence between existing profiles and added concrete, without expansion bolts as shear connectors.

The reinforcement solution has to be always subordinated to a previous structural diagnosis to determine the damage level.

The proposed solution is based in increasing the stiffness and strength of the damaged existing frame, adding a superior concrete slab. The loads are not increased due to the incorporated expanded polystyrene elements. There are other advantages, such as substantial decreasing of vibrations and avoiding of differential deflection, due to the composite action of existing profiles and added concrete.

3.1. Revision of adherence between existing profiles and added concrete

The composite performance is usually assured using connectors, making more expensive and complicated the rehabilitation of ancient frames. In this particular solution the composite performance is guaranteed by the adherence between the existing profiles and the added concrete, due to the geometry of the proposed solution, as shown in the figure 4.
Adherence between steel and concrete elements depends both on chemical adhesion, and mechanical friction between both materials. In spite of several tests, which have proved that adherence is not constant in the longitude (it has a variable non linear distribution); in practice it is common to consider a uniform medium virtual tension. In the Cuban standard NC 207:2003 [5] the following expression is used.

\[ \tau^*dl = 0.3\sqrt{R'b'} \]  

We have also used the following expression to determine the force generated by adherence tensions.

\[ N^* = p\alpha \times ld \times \tau^*dl \]  

where:
- \( N^* \) – Force generated by adherence tensions.
- \( p\alpha \) – Perimeter of adherence between profile and concrete slab.
- \( \tau^*dl \) – Adherence tension.

3.2. General considerations
In the conception of the proposed solution, several considerations are taken into account:

3.2.1. Homogenised section
In limit state design we have considered the following expression and diagram:

\[ n = \frac{Eap}{Eb} \]  

where:
- \( n \) – Equivalence coefficient
- \( Eap \) – steel modulus of elasticity
- \( Eb \) – concrete modulus of elasticity

![Fig. 5 Real section and homogenized section](image)

3.2.2. Neutral axis of homogenised section
To determine the position of the neutral axe different expressions were used:

\[ X = \frac{A_n \cdot R_{ap}^*}{0.68 \cdot b_y \cdot R_y^*} \]  

\[ S_1 = \frac{b_y h_t^2}{2} \]  

\[ S_2 = A_n V \]  

\[ X_1 = -\frac{An}{br} + \frac{\sqrt{An[An + 2br(h - V^*)]}}{br} \]  

870
\[ I = I_n + A_r (X_c - V')^2 + \frac{brX_1^3}{3} \]  \hspace{1cm} (8)

\[ X_c = h - X_1 \]  \hspace{1cm} (9)

where:
- \( X \) – Position of neutral axis
- \( S_1 \) – Static bending of effective reduced area in added slab respecting to an axe contained in its surface contact with the profile.
- \( S_2 \) – Static bending of metallic profile respecting to an axe contained in its surface contact with the slab.
- \( A_n \) – Net area of profile cross section
- \( X_1 \) – Position of the elastic neutral axis in the homogenised section, measured of the superior edge.
- \( X_c \) – Position of the elastic neutral axis in the homogenised section, measured of the inferior edge.
- \( I \) – Inertia of the homogenised section
- \( I_m \) – Inertia of profile cross section referring to its centroid axis.
- \( V \) – Distance from profile superior edge to its gravity centre
- \( V' \) – Distance from profile inferior edge to its gravity centre
- \( h_o \) – Concrete slab thickness
- \( h \) – Total height of the composite section
- \( br \) – Concrete slab effective width

**Fig. 6** Position of neutral axis

To determine the resistance capacity of the compressed concrete slab, different hypothesis have been considered:
- The traction resistance of the concrete slab is not considered.
- The steel bars used in the concrete slab are not considered in compression.
- The concrete slab and the existing profiles will not be separated in any point of the longitude.
- In the case of complete interaction, the calculus diagram for concrete will be considered as rectangular; with a width equal to the equivalent rectangle of the parabolic diagram, with height equal to 0.8X, being X the height of the plastic axis, and width equal to 0.85 R \( b^* \)
- Resulting traction and compression forces are equilibrated in respect to the neutral axis.

4. **CASE STUDY**

The solution was applied in a case study, a building settled in the San Isidro sector, in the Historic Centre. The procedure applied included different non-destructive tests in order to estimate the residual resistance of the damaged structure. The procedure applied included different non-destructive tests, in order to estimate the residual resistance of the damaged structure.

The structural diagnosis included:
- Deflection measuring.
- Removing of non-structural materials.
- Measuring of real profiles cross sections.
- Research of ancient design standards.
- Comparison of real profiles cross sections with nominal cross sections.
- Determining residual capacity and type of reinforcement.
A quality control was applied in order to assure the correct implementation of the model. The underpinning process and setting of expanded polystyrene elements is shown in the following figures.

The building was finished and it is being used as a commerce downstairs and two apartments upstairs.
5. CONCLUSIONS

- It is feasible to propose the use composite construction concepts in the rehabilitations of ancient buildings. The reinforcement solutions have to be always subordinated to a previous structural diagnosis to determine the damage level.
- It was proved that the proposed solution increases the stiffness and strength of the damaged existing frames, decreasing vibrations and voiding differential deflection; due to the composite action of existing profiles and added concrete. Loads are not increased due to the incorporated expanded polystyrene elements.
- The solution was set forward in a case study, in which a quality control was applied in order to assure the correct implementation of the model.
- Taking into account that the structural typology of frames made of metallic profiles and concrete or ceramic slabs is wide spread in the Historic Centre of Havana, the proposed solution may be applied in several cases.

ACKNOWLEDGEMENTS

Havana city's Historian Office OHCH
Superior Technologic Institute José Antonio Echevarria ISPJAE
Eng. Odalys Alvarez Rodriguez, PhD.
Arch. Pedro Tejera Garofalo, PhD.
Eng. Rafael Larrua Quevedo, PhD.

REFERENCES