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Elements of Structural Reinforcement in Heritage Buildings

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***Abstract* – An important role in a good construction design in structural compliance is the provision of appropriate structural connections. Since the beginning of construction, the use of durable materials and the use of appropriate techniques have been the main concerns of builders. The appearance of metal represented a progress in the realization of sustainable constructions, successfully responding to critical situations generated by elements subject to stretching. The authors develop an important topic in the structural analysis of heritage constructions made during the 15th, 16th, 18th, 19th and early 20th centuries, when the connections of the opposite walls were made with tie rods made of metal plates embedded in the floor structure and anchored on the facade of the walls through various practical but also ornamental anchoring systems. At the same time, they also applied to the anchoring of the shield walls on the attic area, the frames, the gables, etc.**

Keywords – heritage buildings, metal anchors, restoration

1. INTRODUCTION

In the period from the 14th century to the 18th century, wrought iron, as a basic product of steelmaking but also motivated by the high degree of universality in the various fields of use, was used in the field of construction for doors, decorative elements, structures in the form of tie rods, embedded in masonry in buildings with two or more levels or visible in cathedrals or medieval churches. Starting with the 18th century, wrought iron found its applicability in beams, stiffening elements of floors and frequently used in combination with wood and masonry. The special resistance to stretching gave the field of use a diversified range of applications, where the elements had to be stiffened and the capacity of classic materials, such as wood and masonry, was long exceeded. It can be observed in many buildings that the metal construction elements remain hidden in the form of braces in the solid masonry of load-bearing walls, whether they are visible, as in vaults or arches. Instead, it can be observed that their anchoring can also be embedded or apparently on the facade, as it appears in many buildings, the anchoring systems appear on the facades as artistic elements. The 18th century is the one that recognizes metal as a key element of buildings and the only one capable of ensuring the constructive balance of the ensemble. In fact, the aesthetic value of the metal was highlighted by the quality of the built assembly.

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2. TYPES OF TIE RODS AND ANCHORS

The conservation and rehabilitation of the structures of heritage buildings requires, first of all, to understand correctly how these structures were thought and built, the methods and techniques applied. It is necessary to know as well as possible the materials and construction techniques used in the era in which it was built, as well as the level of knowledge in the field at that time.

Fig. 1 Floor made of metal beams on which brick vaults discharge [7]

The anchor represents the structural connection element of two walls, an arch or a roof structure or the attachment of the gable element from the main facade to the floor or the frame element or the heels in the console, to other elements with a stable structure (for example: frame, floors).

Anchor plates have been used since ancient times and are placed on the exterior walls of the building's masonry. Being visible, many anchor plates are made in a decorative style. Their form is closely related to the culture and civilization of each people, customs and traditions.

The anchor is the solution for embedding a tie rod in the form of a bar or plate that is usually required in tension. These elements have been used since ancient times, at first they were made of wood, and later of wrought iron. We find wooden ones at the church of Saint Nicholas, Bâlteni village, built at the end of the 16th century Figure 2. [7].

Fig. 2 Wooden truss - St. Nicholas Church, Bâlteni Village, Periș, Ilfov County [7]

In normal operating environments these tie rods performed very well.

In the case of wooden tie rods, if a humid environment persists inside the constructions, damage caused by biological attack may occur (wood degrades as a result of the action of fungal attack).

Later, with the development of metal processing, metal tie rods in the form of bars or chains such as those in Figure 3, Figure 4 and Figure 5.

Fig. 3 Metal truss - Blue Mosque in Istanbul (17th century) [11]

Fig. 4 Iron tie rods at the entrance of the Atik Ali Pasha Mosque Istanbul (15th century) [12]

Fig. 5 Metal tie rod arch of the vault of St. Nicholas Church, Buzău County [7]

In the case of wrought iron tie rods, the most common form of damage is caused by their excessive corrosion. In the areas where the deterioration of the wrought iron tie rod is more intense, openings/discolorations of the material can be observed. Also distortions of the pretensioning devices, as a result of movements in the structure such as the examples in Figure 6 and Figure 7.

Examples of damage to the iron tie rod:

Fig. 6 Tie rod tension and interior of the Atik Ali Pasha Mosque in Istanbul (15th century) [1]

Fig. 7 Tie rod yielding in the central area, the Palace Edirne - kitchen building (15th century) [1]

Fig. 8 Palace Edirne kitchen building (15th century) [4]

Due to its geometry, the kitchen building of the Edirne Palace in Figure 8 it does not have the same behaviour in operational loads and exceptional loads. During the earthquake, deformations occur in the vaults, at which point the tensile braces are required.

3. THE ROLE OF TIES RODS AND ANCHORS

Tie rods play a decisive role in controlling horizontal thrusts produced by static loads (acting on vaults and arches) and/or dynamic loads induced by earthquakes. In the case of historical buildings, the tie rods are either mounted during the initial construction of the building, or they were inserted later, as a structural necessity that became urgent in an earthquake, of a subsequent increase in load arising as a result of a change in the building's function, during repairs, bumps, etc. The installation of metal braces has remained, even in our most widespread technique for strengthening the historic days of masonry, especially in seismic areas.

Although tie rods have been widely used in historic buildings, there are relatively few studies regarding their historical and technical characteristics. The most remarkable researches based on archaeological methods were carried out in France, at medieval monuments in the Gothic style. The main purpose is to date and locate the use of iron as a building material and to obtain information about how this period was processed in that period. However, the studies were limited to the northern part of France and did not provide much information regarding this mechanical behaviour in tie rods.

A very small number of studies refer to the evaluation of the strengths of existing tie-rods, most of which refer to new tie-rods. The studies carried out on the tie rods of historical constructions mainly analyze their response to static loads using linear elastic or elasto-plastic models, which is why the metal tie rods are modelled by hypotheses simplified, respectively they are checked against the parameters of modern steels and not at all based on experimental tests of the original materials. [8].

The anchors are elements that allow the solidarization of tie rods and have the role of connecting structural components and ensuring resistance and stability in operation, especially seismic actions. The anchor plate is the plate attached to the element that allows the connection. The plate can be visible on the facade of the building or hidden, embedded in its structural elements. At the same time, the plate can be replaced or supplemented with an ornamental element.

Anchor plates (or anchors) have different shapes and sizes. According to [6], an anchor plate is specifically a "wrought iron clip, of Flemish origin, on the outside of a brick wall that is connected to the opposite wall by a steel rod to prevent dislocation "their". In the past, these clips could represent the building year or the owner's initials, later adopting different ornamental forms.

A common anchor plate pattern is still stellar - a cast or machined anchor plate in the shape of a 5-pointed star.

Fig. 9 Star anchor, the anchor plate in the shape of a star with 5 corners – Washington D.C. (U.S.A.) [18]

These star-shaped "bolts" are basically tie-rod end anchor plates or anchor systems to other strength elements. They are connected to a long threaded rod, and the rod is connected to existing beams, transverse walls, so basically to the structure of the house. Their role is to anchor structural walls to structural walls.

Anchors are made of cast iron (wrought iron or steel) and are used in masonry construction. They are commonly found in many historic settlements, both urban and rural in Europe and areas of the U.S. (New York, Philadelphia, St. Louis, Cincinnati, Charleston, Washington, South Carolina, as well as in the area of high seismicity like San Francisco). In these areas there are a large number of brick constructions from the 18th and 19th centuries. The assembly consisting of tie rod and mesh strengthens the masonry wall against a possible lateral tilt, or detachment.

In Roman technology, wooden beams (or braces) were used between the arches to negate external horizontal forces between them.

In the modern era, braces are made of iron or steel and serve to strengthen vaults, arches and, in general, masonry structures. In load-bearing masonry structures, the walls have embedded in their thickness the metal brace arranged between the parallel walls at floor level, which creates a state of horizontal compression, thus increasing the shear resistance of the wall.

Fig. 10 The position of the tie rods with ornamental anchors at a historical tower, Alba Iulia City

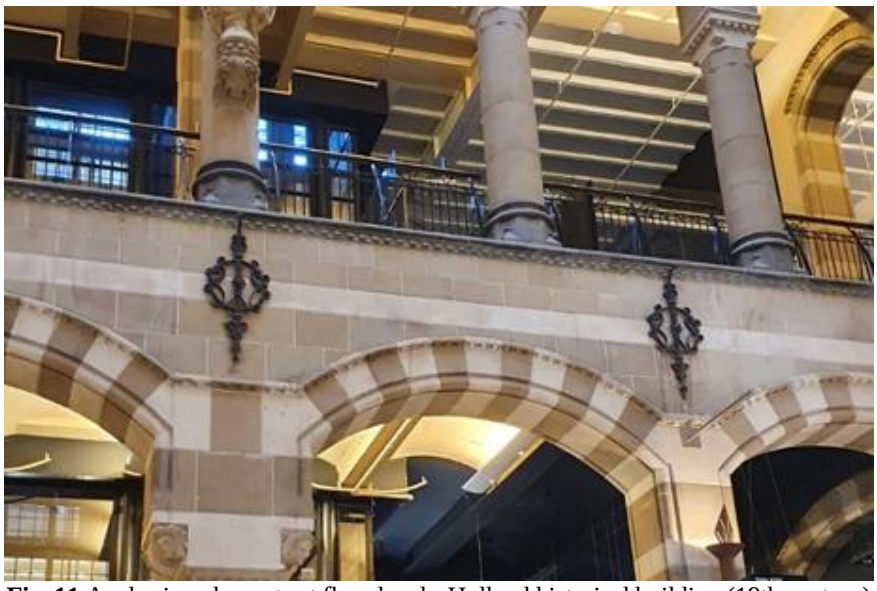

Fig. 11 Anchoring elements at floor level - Holland historical building (19th century)

Fig. 12 Multi-storey building with metal anchoring elements next to the floors - Netherlands

While most types of anchors are made of steel only, anchor plates can also contain malleable or cast iron.

Sheave wall is most often made from a cast iron star or flat steel.

Fig. 13 Anchor types – detail

Fig. 14 Ion Pâslă House, Constanța city

During seismic actions, but also in situations generated by deformations, corrosion or displacements of the land, these anchors can fail, their role being cancelled. In the image, a tie rod from a construction made in 1910, in Constanța, exposed to corrosive factors from the marine environment, but also to the lack of maintenance work at the level of the bridge.

Fig. 15 Tie rod detail at the intersection of the exterior load-bearing walls of the facade

Corroded tie rods that no longer cooperate with the masonry. The effect of working walls at intersections is completely exhausted. The area had masonry expelled under its own weight. Area of intersection of load-bearing facade walls, floor 1 - intersection of Sulmona Street- Ovidiu Square, Constanța city.

Fig. 16 A detail of tie rod with anchor highlighted in the situation of a building being demolished. Image of building built in the 2nd part of the 19th century in D. Bolintineanu Street, Brăila city

When the anchorage length or the anchorage system is not, the flow level can affect the loss of stability of the anchored element. An eloquent example in this sense is the tie

rod of the Church in Nicolae Bălcescu village in Constanța County - you can see the yielding of the arch in the area of its birth.

Fig. 17 The church of Nicolae Bălcescu village, Constanța County

Another application of these anchors is the connection and anchoring of the heels, of the gables of the existing frame. This solution is the most often used, but involves, in almost all cases, the strengthening of the existing framework, and sometimes also the strengthening of the masonry (for example by cladding).

Fig. 18 Anchoring the pediment by means of an inclined plate. Building, Sulmona Street Constanța City

Apparent horizontal tie mounted next to the wall. The section is affected by corrosion.

Fig. 19

Fig. 20

Anchoring the side fenders by mounting tie rods between the wooden beams of the planks. Buildings, Danubius Street, Brăila City

Fig. 21 Anchoring the gables, Holland

Fig. 22 Anchoring the pediment, at the level of the bridge, to the frame with the creation of ornaments in the shape of an eight-pointed star on the facade of a memorial house in Brăila

Fig. 23

Fig. 24

Pediment anchors masked by circular ornaments arranged in the architecture of the facade

The aesthetics of architectural forms made of iron acquired a wide market in the urban environment and in the 19th and early 20th centuries, being found mainly in all minor architectural elements. The phrase minor architecture does not refer to the quality of the architecture, but refers to a dimensional ranking of metal elements, namely: awnings, verandas, canopies, skylights, balconies, and others.

Fig. 25 Brăila State House

Fig. 26 Amsterdam Hotel

Fig. 27 The dome of the Maria Filotty Theater in Brăila City

It is difficult to identify the provenance of certain elements, because the variety of models betrays some particularities of the manufacturer. A specific element is their anchoring to the resistance structure.

At the beginning of the 19th century, the balcony was a component that adorned and beautified any facade, being an element appreciated throughout Europe. Even the attitude of the authorities was beneficial for the use of iron, both for reasons of resistance, but also for reasons of protection against fire.

Fig. 28 Balcony of a private real estate

Fig. 29 Balcony of a private real estate Mihai Eminescu Street, Brăila City

Promoted in the second half of the 19th century, the architecture of the commercial street brings a substantial intake to the promotion of metal, as an element of resistance of the minor architecture and which manifests itself through the consoles of the awnings, wide shop windows, the local abandonment of the massive masonry enclosure and their replacement with a load-bearing metal structure, or even inside the commercial space, abandoning the load-bearing masonry and replacing it with metal pillars with beautifully ornamented brackets.

Fig. 30 Central image from Brașov City

Fig. 31 Image from Ovidiu Square, Constanța

The balustrades of the balconies, as well as the balustrades of the internal stairs, become ornamental elements made by artists.

Fig. 32 The banister of the interior stairs

Fig. 33 Constanța historical monument staircase

4. CONCLUSIONS

The use of metal in civil engineering was a modern phenomenon, manifested under the highest demands, in the southern area of the Carpathians and represented an attitude in the promotion of both modern materials but also in ensuring the resistance and stability of the construction.

This allowed the realization of some unique elements, representing the stage of a development specific to both Europe and Romania. It applies mainly to civil constructions and has contributed essentially to the development of knowledge in construction techniques.

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