Study of rehabilitation solutions and reinforcement of timber pavements

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1. Introduction

Until the beginning of the 20th century, wood was “the” structural material present in all Portuguese buildings. Most of those methodologies are still use nowadays. Wood has proved to be a material with excellent mechanical characteristics and durability, especially when preserved correctly.

However, over time there was less concern with timber structures and their rehabilitation and conservation, not only because of new and more competitively priced materials that appear on the market, but also due to the lack of knowledge about the qualities and potential of wood.

It is essential to encourage the practice of careful rehabilitation, associated with the need to preserve the architectural heritage of both historical and current buildings and contribute to a more sustainable construction.

This study intends to demonstrate the viability of old timber pavements preservation / rehabilitation, developing an overview of the various reinforcement / rehabilitation methods available to solve several identified structural anomalies.

To illustrate the presented methodology, two case studies are presented, where the structural rehabilitation processes of timber pavements played a prominent role. A brief description of the morphology of these 2 cases is made and is also reported how the rehabilitation interventions alternatives were evaluated.

In short, the main objective is to set out, in a real context, how the rehabilitation of a timber structure should be approached and which phases of this process contribute to the correct verification of the stability of the final timber structures.

2. Wood, the material

Given its organic nature, wood is a complex material, structurally and morphologically, with great variability of its physical and mechanical properties. It can be defined as a heterogeneous and anisotropic material.

As structural element, wood has been replaced over time by other materials, such as steel or concrete, with better resistant capacities. However, wood has advantages compared to those. Wood’s high durability, its relative strength-to-weight ratio which allows lightweight structural elements and the fact that it is a recyclable and sustainable material, are some of those advantages.

The type of wood, namely, the botanical species of which it is part, is the factor that most influences the properties of the element, because it dictates its morphology and organic constitution.

The variation of wood water content influences its mechanical strength, maximum when the wood is dry or anhydrous and minimum when fully saturated.

The moisture also influences the deformation that the material undergoes when subjected to a load. Frequent cycles of absorption and release of water increase the creep value. It also increases timber structures deformation and may cause the material rupture before reaching the maximum load.

Wood resistance capacity is linked to the existence of imperfections in the fibers, namely nodes, slits and direction of the grain.

Regarding the duration of loads, timber structures have a larger load-carrying capacity for short term load when compared to their failure load for long-term. (Branco, 2003). This property makes timber structures with great efficiency under dynamic loads, as wind and quake, given their short-term duration.

3. Timber structures rehabilitation: Anomalies and Solutions

In recent years, the rehabilitation of old buildings has become increasingly important in a way that is simultaneously related to the need to promote preservation of the architectural heritage and the growing awareness that it is a potentially very interesting activity for designers and builders (Appleton, 2003).

The increasing idea of rehabilitation rather than new building it's today seen as a plus for the construction sector and a strategy for the future.

The construction community is now more aware that conservation theory is imperative, not only in the case of buildings of relevant architectural heritage, but even also in current buildings.

The replacement of timber structural elements can be selective and its structural repair can be punctual, depending the parts affected by biologic organisms or by rot, which can be removed and replaced by prostheses of identical wood.

Thus, it is up to the designer to analyze, in the pathology found, the best solution or intervention to be adopted, taking into account the characteristics not only of the part in question, but also of the entire surrounding structure.

In (Pereira, 2017) are discussed the main anomalies that can be found in old buildings with a timber structure and, for each case, examples of possible solutions focusing on the study of timber pavements, are presented.

The main anomalies in timber pavements are related to the presence of water and consequent effects on the construction (Appleton, 2003).

Infiltrations caused by precipitation affects pavements and represents the biggest concern in both case studies and hereby lead to structural problems.

Insufficient section: It can occur due to the attack of biologic agents, to an increase of the loads and to a poor design. It is detected when excessive deformation occurs or when local cracks in the pavements structure are visible.

Excessive deformation: The creep of wood, the presence of imperfections, the insufficient section of elements or the elimination of bearing walls may result in excessive deformation. This problems can appear from different reasons such as variations of the applied load system, excessive spacing between the main beams and unsafety structure design.

Support problems: Support zones are areas favorable for presenting pathologies due to the high levels of humidity they suffer, they cause the attack of biological agents.

Buckling: Normally buckling is a phenomenon of instability that can occur in the elements subjected to compression and which can lead to failure of the structural element or to the progressive collapse of the structure. The way to avoid these deformations is through the placement of bracing elements, which prevent their development.

Cracks: Cracks and warping on timber elements of old buildings have their origin in uncontrolled cycles of humidity and drying. The cycles of moisture and temperature, cause volumetric variations of the elements leading to the opening of cracks. The most frequent form of treatment and elimination of these problems consists on the use of epoxy resins and metallic elements, which allow the sealing of the slits and the reduction or elimination of the warpage.

In order to respond to those problems and anomalies, in each specific case, we must evaluate the present safety and then the expected levels as a result of existing actions.

The increased cross-section of the elements is achieved by the attachment of new pieces of wood to the original elements with metal plates or bands and nails placed to join the two elements together.

Excessive deformation can be essentially limited by two distinct processes:

- Reduce the span of the pavement, creating intermediate supports (for example, by constructing cross beams to the pavement beams);
- Strengthen the resilient capacity of the pavement by increasing its rigidity and reducing deformability.

The support zone of the beams are places with a high risk of degradation, particularly when the wood is high in water. In these conditions, and even if the rest of the part is in good condition, it is necessary to act to recover the safety conditions that are compromised.

It is essential in rehabilitation of timber pavements to ensure an effective connection between the new beams and the supporting walls.

The repair, partial replacement or reconstitution of wood sections may be carried out through different processes depending, among other reasons, of the cause of the anomaly.

One possibility is to remove the damaged zone and replace the rotted top with an identical piece of the same material. The connection between the two parts can be done through auxiliary elements:

- The most generalized solution corresponds to "splicing" the degraded beams, through the application of new timber elements, of one or both sides of the existing beam, without removing the damaged areas;
- Placing of metal plates applied to each of the faces of the beam, bolted with screws that cross the beam;

Both these “techniques” are explored in the case studies presented in (Pereira, 2017) that are now resumed in the next pages.

The two solutions presented apply connections with metal fasteners as a mean to put the two beams together (the original and the old one)

Connections are usually the weakest points of a timber structure. Because they are subject to concentrated stresses and strains, they require careful attention so that the overall safety of the structure is not jeopardized.

Related to connections it may be said that for the same situation there are several ways of connecting two elements, depending on the purpose, the efforts and the working loads.

Like the limit state safety design, the European regulation for the metal fasteners connections is Eurocode 5 - Part 1.1.

4. Case Study – 3 Floors Building in Rua da Esperança do Cardal

In (Pereira, 2017), two case studies are presented to consolidate, in a more practical way, all the theoretical knowledge referred to.

The first building analyzed, dating from 1933, is located on the eastern slope of Avenida da Liberdade, at Rua da Esperança do Cardal, a narrow street typical of the neighborhood in which it is located. It is a building of 3 floors, with an area of 150 m^2 each.

During the monitoring of the work, problems were identified in the pavements, caused by infiltrations near the exterior facades. Those infiltrations caused the degradation of some of the floor beams, weakening them and forcing them to be replaced.

The design and safety verification of the timber structures follows a methodology similar to the study of reinforced concrete or metallic structures.

Eurocode 5 (EC5) responds to issues directly linked to the wood specifications, with a synthesis of the regulatory provisions of timber structures.

The replacement of the beams could be total or partial. A partial replacement makes sense in situations of timely damaged beams or when the access to the work is difficult, as is the case here presented. In the decision to partially or totally replace a compromised beam, not only the technical aspects, but also the operational and cost factors should be taken into account.

Figure 4.1 - Photographs of timber pavements degradation state in Rua da Esperança do Cardal

Regarding the structural rehabilitation of the existing timber pavements presented in this first case study, several alternatives of intervention were designed and presented to the building owner, with the respective budgets.

Three alternatives were presented.

In the initial analysis of the poor conditions of the existing framework, we conclude that the beam damage in all floors was, on average, up to about 30 cm of the support. Therefore, those 30 cm were considered as the cut-off zone for all the interventions adopted.

According to the concepts and security conditions described in (Pereira, 2017), the verifications were made to limit states of the original solutions and the design of the proposed connections.

All the three interventions uses connections with metal fasteners. Hereby, it is important to define the design of the connections and their safety.

The first step in connections design is to understand how the loads and the driving forces are distributed and how they are transmitted to all the elements of the connection. It is necessary to know what type of requests each component is subject to.

In the case of metal fasteners, it is the most conditioner fastener that determine the connection strength.

The strength of the connection depends on the strength of each component, namely the strength of the wood in the required various directions, the strength of the metal binder, if applicable, and the failure modes (Pereira, 2017) that may arise in the timber beam.

The first solution is a splice with metal plates and bolted.

The second proposed solution was designed in such a way as to take advantage of a notched system between the cut pieces of wood. Bevel rather than vertical cutting reduces the shear force on the fasteners as the force shear force decomposes into two smaller components.

From the economic point of view, this solution becomes significantly cheaper than the other two proposals. However, the bevel cut can bring complications to the workforce and is not, in practice, so easy to perform.

The third and final proposal for intervention was the solution initially envisaged by the project designer. The intervention consists on cutting of 30 cm of the existing beam (damaged zone) next to the support and replacement by a new beam that will be spliced to the existing one with 2 lateral wood pieces, with screws.

For each of the different solutions presented, an economic study was made. It was decided to request a budget from a construction company, in order to obtain the values as close as possible to the current real market.

A discriminatory budget was requested between materials and labor. To control the scale effect on unit prices, it was defined that the quantity of each type of intervention was of the order of ten.

Regarding the materials, class of resistance C18 was considered in the sections indicated, foreseen in the project. Plates and screws galvanized in the indicated dimensions and classes.

From the requested budget you have the following prices, per proposed solution (€/solution):

- Solution 1:Top-to-top reinforcement with lateral metal plates - 131,30 €
- Solution 2: Splice by overlapping tops with half miter and bolt-on fastening - 65,90 €
- Solution 3: Parallel joist joint and bolt-on fastening – 118,50 €
- Solution 4: Integral substitution of the beam – 228,00 €

Clearly the cheapest solution is solution 2, where the major difference is the cost of the required material, as it requires fewer fasteners and a smaller diameter and length. However, the bevel cut may be a more delicate intervention and may weaken the part if it is not well executed. That is, it is an intervention that requires more specialized labor.

Solution 3 was the intervention chosen by the designer to adopt in Rua da Esperança do Cardal, as it was referred to as a more traditional solution usually performed in rehabilitation in Portugal.

Solutions 2 and 3 have the advantage of requiring fewer materials than Solution 1, and the less varied and easier the material to acquire, the better. Solutions 1 and 2 require more precise work, as has already been said.

Concluding, although solution 2 is the cheapest, it has some concern about the stability and correct assembly of the connection. The most appropriate solutions are Options 1 and 3, and within these two, it is up to the owner and designer to choose the one that fits best in the characteristics of the pavement in question.

As a curiosity, was also asked for a budget for the complete replacement of the beam – Solution 4. Because the existing beams were continuous throughout the length of the building, a total of 8 meters, the price of the wood beam per meter linear was very expensive. Comparing the price of partial intervention solutions with the integral replacement solution, it is confirmed that a partial replacement of the damage beam is cheaper.

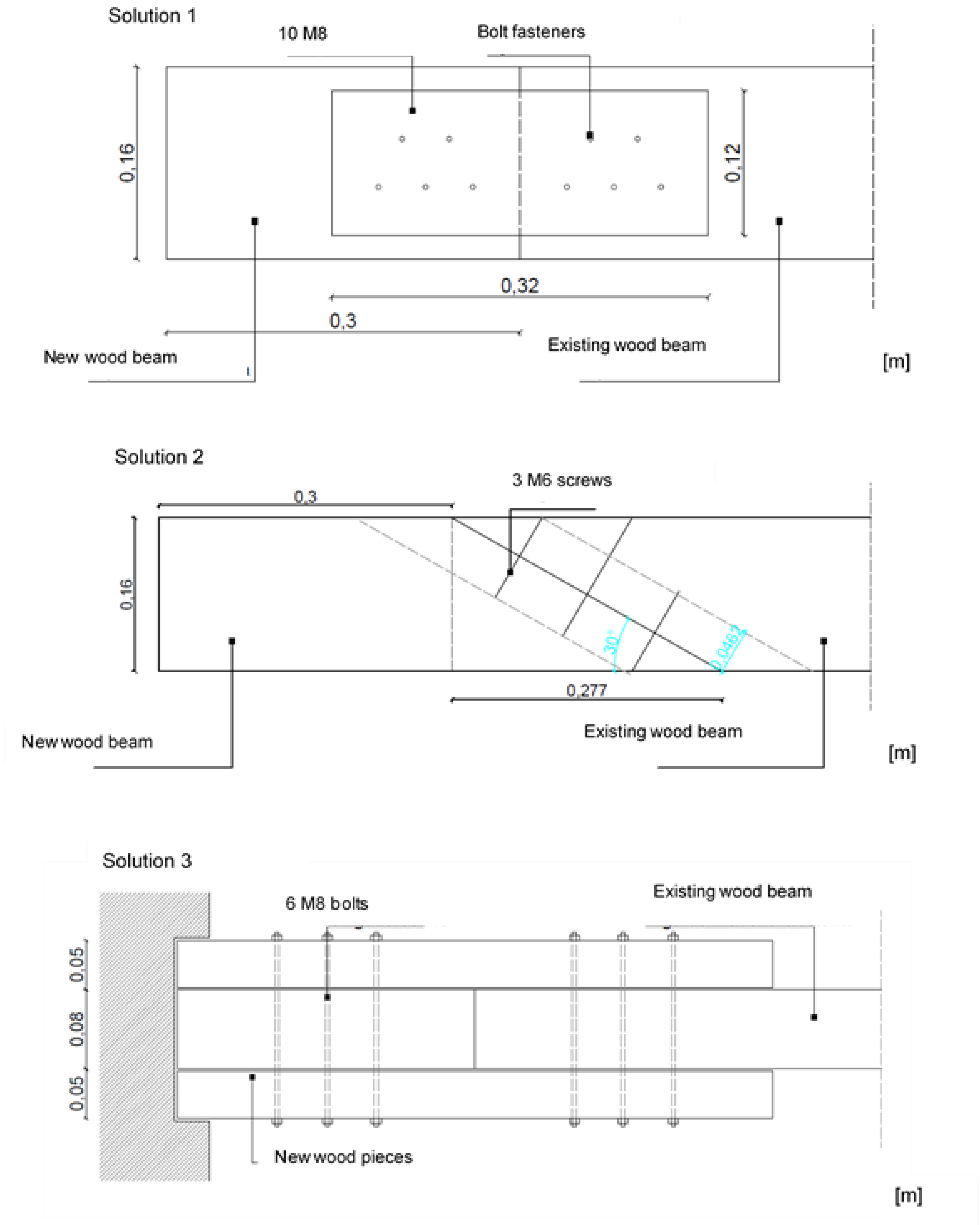

Figure 4.2 - Intervention alternatives presented – Solution 1 (top); Solution 2 (middle) and Solution 3 (bottom)

5. Case study – Faria's Palace- Príncipe Real

The second case study presented concerns the rehabilitation of theFaria's Palace, located in Praça do Príncipe Real and dating from 1890, and another building: old mansions of the Palace, with entrance by Travessa do Abarracamento de Peniche, from 1892.

In Faria's Palace there was some structural insufficiency in terms of timber elements of the pavements, in particular the absence of doweling, which causes the generalized buckling of the timber beams in the areas of greater span.

However, based on the inspection and analysis carried out, we can conclude that the safety of the Faria's Palace was not severely compromised, since it is a robust building with a reasonable state of conservation.

The plan of reparations is based on the reconstruction of the integrity of the damaged parts using epoxy resin or wood pieces, in order to allow the execution of the works without the need for structural disassembly.

In case of the replacement of timber elements, traditional techniques we followed, using connections with metal parts in the amendments to be made.

A similar solution to the one described in the first case study was used by the engineer.

Figure 5.1 - Photography of intervention in timber pavements in Palacete Faria

In the first instant it was planned to use two lateral wood pieces bolted to unite the new wood beam and the existing one. However, the space between two parallel beams was not enough. So the second and effective alternative adopt was a top-to-top joint with reinforcement by means of lateral metal plates.

Figure 5.1 - Photography of the intervention adopt

6. Conclusions

Throughout the text we highlight the message that wood is a construction material that has very complex characteristics, and depends on their species and the conditions to which the elements are subject. For these reasons, assessing the robustness of existing structural elements and the calculation values to old wood is a complex process.

A comparative analysis was carried out in order to define the most appropriate rehabilitation / reinforcement solutions for the different cases, evaluating their simplicity of implementation; Improve strength and stiffness; Space occupied and visual impact.

The aim of this survey was to create a practical manual that can be consulted and useful in the perception of the intervention options that may exist in the face of a certain type of anomaly.

To be notice that this "manual", is a sample, and an exhaustive analysis has not been done, but only a practical and generic nature study.

In conclusion, the rehabilitation of buildings and the structural evaluation of structural elements in wood are increasingly discussed, and inevitably are part of the future of Portuguese construction. Not only due to the growing culture associated with the preservation of the existing historical patrimony, but also for environmental reasons, since this is a natural and renewable material.

There has been a development of the knowledge of the mechanical performances of the wood and the means of execution of the connections, whose improvement not only brought a greater dimensional accuracy but also allowed a greater freedom in the architectural forms, making wood a more competitive material such as concrete or steel.

7. Bibliography

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