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TIMBER ELEMENTS: TRADITIONAL AND MODERN STRENGTHENING TECHNIQUES

BY

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Abstract. The main idea of this paper is to analyse the means for the rehabilitation of our cultural heritage timber structures. Several methods together with their application techniques are described, and also, the reasons for what these strengthening operations become imminent at a point. First of all, the necessity of the timber structural elements strengthening is explained through a short presentation of the factors which are degrading the material. Then, certain precautions and strengthening procedures are presented, all involving the usage of traditional materials like wood, metal, or concrete, and of modern materials like fiber reinforced polymeric composite.

Key words: timber structure; aesthetic aspect; degrading factors; strengthening; wood; traditional materials; composite materials; polymeric composite.

1. Introduction

The success of wood, as a first class construction material, was proven since the time of the first villages; its applications were varied and intense due to its wide spreading, workability, high strength, and low specific weight.

In Romania, wood constructions have a vast occurrence and an old tradition in the civil, industrial and bridge domains. Among the meaningful accomplishments in our country, the churches and monasteries represent a real value for the cultural heritage and conserving them is an important step in our evolution.

The preservation of original timber parts makes it possible for them to fulfill design restrictions, reducing the structure alterations to a minimum in a rapid and efficient manner.

Considering the fact that the strengthening is applied to buildings with a remarkable cultural value, their aesthetical characteristics must be preserved and emphasized [2]. This cannot be easily done by using the rough, thick elements, made of traditional materials. The bluntness and roughness of some of these works can negatively affect one side of the strengthening intervention purpose, as it is shown in Fig. 1.

Fig. 1 – Case studies for strengthening works of beams and columns using traditional materials and methods.

Traditional materials like metal, wood or concrete have been used in strengthening systems worldwide but they disregarded the aesthetical aspect. Nowadays, the modern age brings up front the easily tailored, thin, high-strength and light-weight composite materials whose advantages, especially in this domain, are impressive. Fiber reinforced polymers do not only bring an increase in the strength of the members they work with, but also reduce their size and self-weight and increase their ductility and fatigue performance. The necessity of using such materials is therefore reflected in the need of more subtle yet higher quality strengthening works.

2. Wood Deteriorating Factors

The main goal for the civil engineer is to improve the load capacity of specific elements. Before strengthening structural wood elements, one must firstly understand the reasons for which these elements are deteriorating. There are a number of factors determining the durability of structural wood and they will be shortly presented hereinafter [1].

Timber is a natural building *material* which ages and deteriorates in time, even without the influence of external factors. Its properties depend on the specific wood species, the geographical location where the wood has grown and furthermore on the local growing conditions of every single part of a tree. All the natural imperfections and irregularities are points of weakness in sustaining loads or resisting to other deteriorating factors.

Moisture is the most important factor of influence for all the physical-mechanical properties of wood and it creates favourable growing conditions for agents responsible for wood degradations. Bellow the fiber saturation point, the wood will shrink when losing moisture and swallow when absorbing moisture [4]. When exposing wood to *temperatures* higher than 150°C, its strength will be affected.

The most considered *stresses* in design of wood elements are the bending moment, tensile, compressive and shear forces. Nevertheless, there are other strength properties that are less important but that can also be used, like the torsion, creep or fatigue resistance.

From the *biological agents* point of view, wood is highly susceptible to the attack of fungi and insects or, in some cases, by some marine borers. When analysing this aspect, it is important to realize that, if fungi attack is linked to the moisture content of the wood, insects can attack in any conditions.

In optimum service conditions wood can last without noticeable deteriorations. Special protective measures and chemical treatments are used when the working conditions are not suitable for the timber elements. Protection against fire, fungi, or insects includes chemical treatments which must consider the nature and severity of the risk, the wood type, the eventual previous treatments, and the possible secondary effects of the chemical products.

3. Classical Strengthening Methods Implying Traditional Materials

Strengthening wood structures involves various methods and techniques depending on the final purpose for the intervention, the elements and materials involved, and the importance of the work. Explicit objectives must be set like the intention of keeping the original material and structural concept, the conservation by maintaining the aspect of the elements and structural solution, the modification, restoration or improvement of the bearing capacity, rigidity and other characteristics of the elements and structure [12].

No matter what method of strengthening is chosen, the works must be compatible with the existing structure, so that the coherent assemble to be easily performed. The repairs can be made on the whole length of the element or on certain degraded parts.

Due to environmental factors and biological agents, surface degradations like holes and cracks can appear. Therefore, the repair techniques must imply the injection of wood with resins that fill up these openings and so restoring the wood mechanical characteristics.

Timber structures, more than those made of other materials, show a very complicated deformational behavior, mainly because of the property of the visco-elasticity that wood belongs, in an accentuated way, if compared to other materials, due to the nature of the tissues and the longitudinal position of the fibers. Therefore often it is difficult to assess the cause, the kind and the entity of the stresses which are responsible for the deformations detected.

In the case of eccentric *compressive* loads, when the elements become subjected to both compression and bending, the supplementary efforts that appear are extremely dangerous, compromising the integrity of the entire element. Different strengthening methods have been developed to partially reduce the deformations and enhance the rigidity of the member but, for all of them, the considered elements must be discharged.

The strengthening of the elements subjected to *tension* depends on the loading values and on the possibility of unloading the element during the actual process. When unloading cannot be realized, the strengthening is realized with the help of certain metallic elements and in the opposite case the strengthening can be made using cover plates made of wood, connected with rods (Fig. 2).

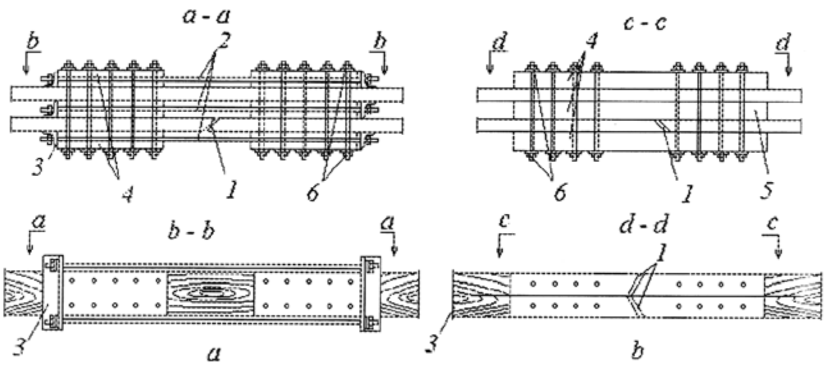

Fig. 2 – Tension elements strengthening [12]:
a – using metallic tie rods, *b* – using cover plates and short inner plates;
1 – degraded area, *2* – metallic tie rods, *3* – L profile, *4* – wood cover plates,
5 – short inner plates, *6* – bolts.

For elements subjected to *bending*, the considered degradations are either cracks situated especially in the middle span area or excessive deformations caused by the change of loads or by long lasting loads. In these cases the local interventions are meant to stop crack propagation or to enclose it. One solution includes the utilization of metallic elements that induce compression perpendicular to the crack and stop its propagation. Two holes are drilled at both ends of the crack and two metallic plates are disposed on parallel sides of the element, bonded with bolts, as shown in Fig. 3.

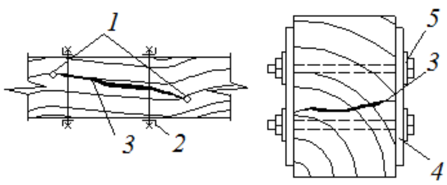

Fig. 3 – Local strengthening of beams: longitudinal cracks [12]:
1 – drilled holes, *2* – clamp, *3* – crack, *4* – plate, *5* – bolts.

When the cracks are perpendicular on the beam axis, one choice would be to use wooden or metallic elements above or under the element, as presented in Fig. 4.

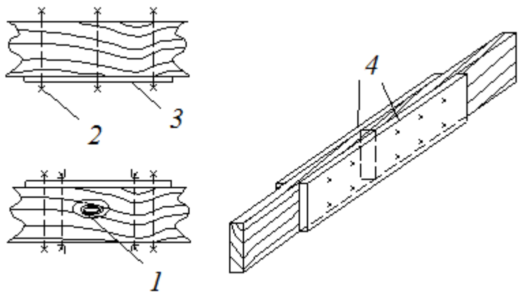

Fig. 4 – Local strengthening of beams: transversal cracks [12]:
1 – degraded area, *2* – bolts, *3* – cover plate, *4* – metallic profiles.

Total strengthening of beams can be made with or without increasing its transversal dimensions. To change the cross-section, new elements of wood, metal or concrete are added above, below or lateral to the existing members. *E.g.*, placing new wooden elements under the existing beams does not influence the secondary elements or the floor; they are linked with metallic anchorages, (Fig. 5 *a*). The same type of anchorages is used for the laterally added elements (Fig. 5 *b*).

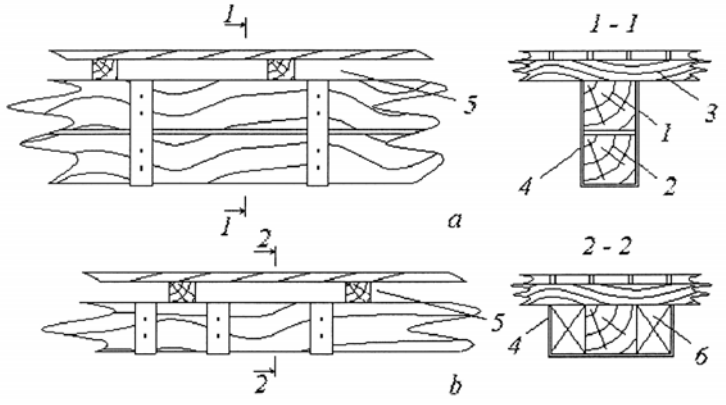

Fig. 5 – Beam strengthening using wood elements [12]: *1* – existing beam, *2* – new beam, *3* – secondary beam, *4* – metallic anchorage, *5* – air, *6* – lateral beams.

When keeping the initial beam dimensions, the strengthening involves the insertion of metallic plates (which have a lower height than the actual beam), of small metallic lattice girders, or of tie rods. The metallic elements must be proofed with epoxy resins. A first layer of resin is poured after the longitudinal pockets for the metallic elements are made. Then, the metallic elements are inserted into the pocket (for the metallic plates case, bolts can be used) and filled up with resin.

Besides this method, another possibility is to use metallic bars buried in the beam which act as tie rods and can be placed laterally or on the inferior part of the girder, with an anchorage at the ends or on the superior part of the wood member. The tie rods can also be placed on the exterior, their distance to the beam being a function of the desired effects on the static scheme of the element (Fig. 6).

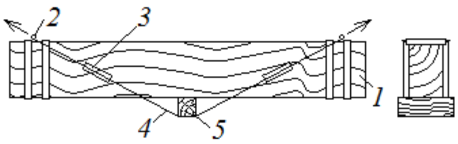

Fig. 6 – Beam strengthening using external tie rods [12]:
1 – beam, *2* – anchorage, *3* – tension element, *4* – tie rod, *5* – spacing piece.

When the damage of the beam consists in the rotting of its ends, usually caused by water absorption through the joints or from meteorological water, the degraded material can be removed and replaced with a new one or it can be strengthened using epoxy resins. This second procedure involves only a partial removal of the material at the ends [3].

4. Strengthening Wood Elements Using Fiber Reinforced Polymer Composite Materials

4.1. Fiber Reinforced Polymer Composites

Composites are made of resins, reinforcements, fillers and additives. A fiber reinforced polymer (FRP) composite is defined as a polymeric (plastic) matrix, strengthened with fibers with a sufficient aspect ratio (length to thickness) to provide certain reinforcing functions, in one or more directions. There are several advantages that make the composites suitable for strengthening works: their light weight, ability to be tailored, high strength-to-weight ratio, corrosion and weather resistance, low thermal conductivity, low coefficient of thermal expansion and high impact strength. They are good insulators, and need low maintenance [8].

The resin function is to transfer stresses between the reinforcing fibers, to act as glue to hold the fibers together and protect them from mechanical and environmental damages. The most common thermosetting resins used in the composites industry are unsaturated polyesters, epoxies, vinyl esters and phenolics [11].

Fibers or reinforcements carry the load along the length of the fiber, providing strength and stiffness in one particular direction. There are different reinforcement shapes which meet the design requirements. The ability to tailor the fiber and to easily orient it in any desired direction brings an optimized performance for the product, also offering self-weight and cost savings. Glass, aramid and carbon (graphite) are the most commonly used reinforcing fiber materials.

Another component for the FRP composites is the adhesive which bonds them together and to other surfaces [6]. The adhesives provide the most efficient method of stress transfer between two materials by avoiding the stress concentrations associated with mechanical fasteners. When applying adhesives, a careful surface preparation and cure must be made to ensure the correct bond performance as it is imperative that a reliable, good-quality connection is established in the hybrid members [9].

4.2. Strengthening Wood Elements Using Fiber Reinforced Polymer Composites

Numerous investigations have considered reinforced wood. Most of these pursuits have involved metal reinforcement while only a few have concerned nonmetallic synthetic fiber reinforcement [5]. Nevertheless, in the domain of composites reinforced wood, certain studies have already been made.

When choosing an FRP composite for this kind of work, there are certain things to be considered like the environmental conditions, the cost limitations, the strengthening method, and the dissimilarities of the materials, which include their moduli of elasticity, surface properties, reaction to creep loading and, most significant, response to moisture and to alternating environmental conditions.

So far, analytical and experimental investigations of wood structures involving external bonding with epoxy resins of thin FRP sheets on the tension zones of wood beams and columns have been performed. The experiments showed that reinforcing the wood members with very thin FRP sheets bonded onto their tension faces has resulted in the increase of the elements strength, stiffness and ductility characteristics. Fiber reinforcements could also be very advantageous in regions of stress concentration (like bolted joints), as well as with tensile and flexural members [10].

Strengthening methods for wood are similar to the ones used for concrete elements. The most common procedures involve sheets or plates of FRP composites, usually bonded with epoxy resin adhesives [7].

The strengthening using epoxy resin is made through several methods, including the removal of the degraded part and the cleaning of the not yet attacked wood.

When strengthening *wood columns*, the compressive loads are to be taken into consideration. When the columns have an affected underground area, excavations are to be made and the considered elements must be supported, cleaned, brushed, and artificially dried. Then resins are injected in the existing cracks and then the surface is covered with epoxy resin and a fabric confinement is made.

Strengthening is possible using *fabrics* with different fiber orientations (0°/90°, –45° /+45° – Fig. 7 *a*). Placed along the column height, *strips* shaped in spirals or parallel to each other (Figs. 7 *b*, *c*), improve the flexural rigidity of the member. For this same purpose, wider straight strips (Fig. 7 *d*), or embedded in fabric confinement *FRP rods* can be utilized (Fig.7 *e*).

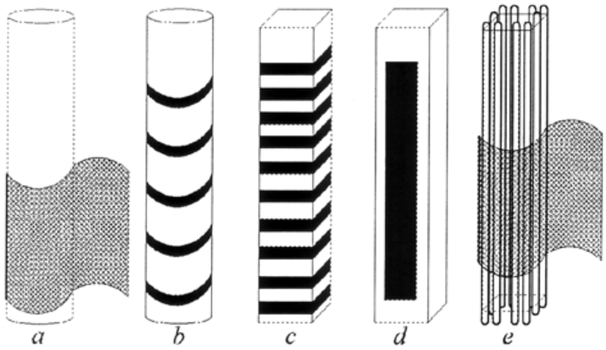

Fig. 7 – Columns strengthening using FRP composites [7].

In the case of *wood beams*, the reinforcing is placed on the bottom part of the element, to strengthen it in the tensioned area, making it stiffer and outrunning its disabilities. The reinforcements are either in the shape of *FRP thin plates* (prestressed or not – Figs. 8 *a*, *b*), covering the bottom part of the beam, especially in the mid-span or supports area, or they can have an "U" shape (Fig. 8. *c*, *d*), jacketing the wood element.

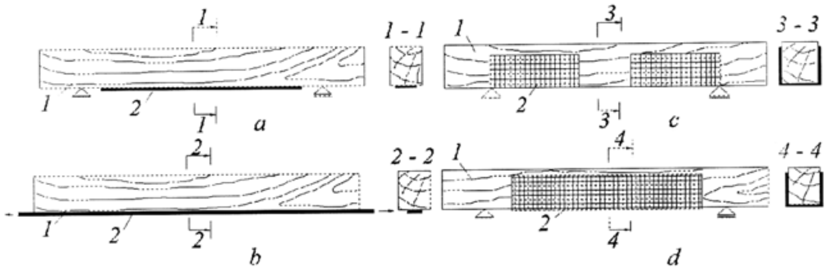

Fig. 8 – FRP strengthening of wood beams [7]:
a – resistance moment improvement using FRP plate, *b* – prestressed FRP plate,
c – shear strength improvement, *d* – shear strength and moment improvement using "U" jacketing ; *1* – wood beam, *2* – FRP reinforcement.

FRP rods or strands are also used, inserted in the wood element in a similar manner with the post-tensioned steel reinforcing in concrete members (Fig. 9).

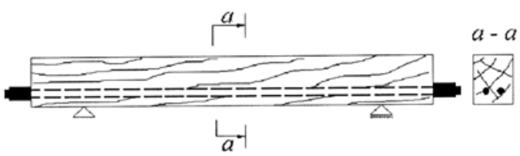

Fig. 9 – Strengthening by using FRP rods [7].

Another used procedure for increasing flexural and shear strength is the near surface montage (NSM). FRP rods are inserted in the channel pockets from the wood surface and embedded in epoxy resin (Fig. 10).

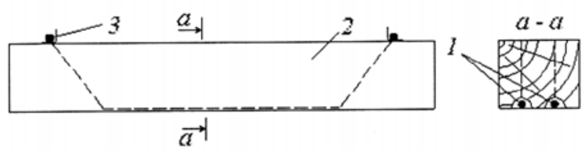

Fig. 10 – Beam strengthening using tie rods at the inferior part of the element [7]: *1* – FRP tie rod, *2* – beam, *3* – anchorage.

5. Conclusions

Old wooden structures like the churches and monasteries of our country (Fig. 11) are part of the cultural heritage and special attention must be given to them. This is where traditional materials like wood, metal and concrete fulfilled the need of preservation but, in the light of the modern way, FRP composites find an easier, more practical and constitutive solution. They are offering a vast range of possibilities therefore, considering the numerous combinations and their great variation, the choice of materials and methods will be up to the designer, for each particular strengthening case.

Fig. 11 – Wood church in Maramureş [13].

For us, to record a progress, both as individuals and as a community, new ways of improving constructions are to be searched for. No matter the domain or the impossibility of an idea, the progress must be encouraged but there should be no possible image of the future without the mark of the past. To keep this mark means to protect our cultural and historical heritage. To achieve this, measures have already been taken but enhanced methods, all following this same goal, are looked for everyday.

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CONSOLIDAREA ELEMENTELOR DIN LEMN FOLOSIND METODE TRADIŢIONALE ŞI MODERNE

(Rezumat)

În lucrare sunt luate în considerare diferite metode de consolidare ce au ca scop conservarea structurilor din lemn ale patrimoniului nostru cultural, fără a se neglija însă prezentarea motivelor pentru care aceste intervenţii devin iminente la un moment dat. În primul rând este explicată necesitatea consolidării elementelor din lemn prin prezentarea factorilor care le degradează. Apoi sunt descrise anumite precauţii şi procedee de

consolidare ce utilizează materiale tradiționale ca lemnul, betonul sau metalul, fiind prezentate şi diferite metode moderne care implică un material relativ nou, compozitul polimeric armat cu fibre.