SUMMARIZED OBSERVATIONS UPON CONNECTIONS OF STRUCTURAL WOOD MEMBERS USING METALLIC ELEMENTS

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ABSTRACT
The proper design and achievement of structural wood member connections are very important factors for exploitation and durability of construction. The purpose of this paper is to present recommendations to designers, contractors and users of wood constructions on how to choose the appropriate type of connection in different situations based on specific structural particularities. In the beginning, the paper describes the main classification criteria of connections using metallic elements and then an analysis of the means of connection design. Further down, the main causes which lead to the deterioration of connection with metallic elements are emphasized and a few explanations having the role to counter-balance these unwanted effects are given. Finally, the paper briefly presents a few connection solutions of wood structure members with metallic elements which are to be avoided and/or repaired in the unfortunate situation when they had already been used.

Keywords: timber structures, connectors, wrong design

INTRODUCTION
In the design of a structure, in general, and of a wood structure, in particular, there are several factors that are to be preliminary considered, i.e. structure configuration, load resisting system, dimensions of elements and workability. For wood structures, the concept and design of connections between members are very important factors in long term behavior and exploitation of construction. Connections between wood elements are necessary, firstly, due to their shapes and dimensions that they are usually delivered in, because most of the time the loading requirements for desired spans and cross sections can not be met. On the other hand, the necessity of connecting one or more elements that converge, forming nodes, appears very often during construction.

MATERIALS AND METHODS
These days there are multiple systems of connections developed by designers and contractors [1], which have been adapted to suit wood particularities and to serve the following purposes:
- forming of built-up sections, when a simple cross section of a certain type of wood used does not have enough capacity to carry the load (interlocking joints);
- extension of wood elements to achieve the desired length (extended joints);
- achieving the required effort transfer between wood elements connected under a certain angle (node connections).

Generally, the connections are created to ensure proper effort transfer under exterior loading. For a given structure, selecting a certain type of connections is not only a matter of strength and loading requirements; there are other conditions such as: architectural aspects, fabrication and erection procedures, costs, etc. [2]. It is basically impossible to specify an assembly of rules which will establish the best system for a certain type of connection, however, when choosing the type of connection [3], the designer shall account for several conditions, of which the following are the most important:
- to minimize the weakening of connected members, meaning to keep as much as possible their initial load capacity;
- to keep the effort flow within the axis of member and to avoid eccentricities which could lead to changes of the load pattern and to necessity of increasing the cross section of connected members;
- to avoid overloading and to ensure uniform distribution of efforts within individual members that are part of built-up elements;
- to balance the efforts between connections and to avoid successive destruction of the joints by using a single type connection with same characteristics;
- to fraction the elements thru which the efforts are transmitted, ensuring a larger number of working sections, in which case the negative effect of possible wood defects can be avoided;
- to avoid negative effect of shrinkage and/or expansion and biodegrading phenomenon (water retaining, insufficient air circulation, etc.)
- correlation between type of connection, type of wood used (round wood, square-edged timber) and environment (interior, exterior, etc);
- to choose the type of connections suitable for shop fabrication, easy to assemble and maintain, and to allow for quality control during erection and building exploitation.

The main elements used as connectors for different types of connections (such as extension, interlocking or node connection) between structural wood members are noted below:
- nails, pre-punched nail plates, screws for wood, bolts, timber dogs, pins [4];
- menig indented connectors, regular indented connectors [5];
- grip holder, clip angles, anchorage straps [4];
- standard connectors with custom modified parameters, exposed gusset plates, hidden gusset plates, cut or bent plates [6];
- metallic spheres for nodes of 3D-systems, mixt systems for columns and beams [5].

1. **Connection degradation of wood**

The existence of wood constructions, sometimes of hundreds of years old, shows that, even though the wood is a natural product, in optimal conditions of exploitation, it could last for a very long period of time, without noticeable signs of degradation. There is a large spectrum of factors [7], generally related to the conditions of exploitation, but not only, which have an influence upon the durability or degradation of wood.

The generation speed of degradation and thus the durability of wood can be controlled thru the design of the elements and use of wood. In this respect, there are several principal directions in which action needs to be taken, such as:
- design and study of details in such way that wet wood, high humidity conditions or point sources of moisture are to be avoided as much as possible;
- avoiding water accumulation in certain areas (connections, supports, etc);
- ensuring proper ventilation of wood in order to quickly evacuate water when temporary moisture is impossible to avoid;
- selecting the type of wood with natural durability in accordance with the environment;
- providing an initial proper treatment of wood conservation.

Of whole factors that lead to wood degradation, the most important is the one related to serviceability; however there are additional factors that could appear during construction’s lifetime, such as earthquakes, high temperatures and fire, changes of occupancy, additional loading or exposure to biological xylophagous agents (fungi, insects).
The design and assembly concept of a structure [8] have to take into consideration the fact that the structure itself has to provide strength capacity under all possible load combinations which can affect the safety and serviceability during construction’s life time. In consequence, the design shall consider all the loads due to human activity (live loads, dead loads, reactions and accidental loads such as fire or overloading) and loads due to natural factors [9] [10] (wind, seism, snow, flooding, water accumulation and landslides). There are two components of the design that require a careful analysis: load combinations and temporary loads during constructions. The first one assumes the combination of loads having a high probability of occurring simultaneously during construction’s life time. The second one refers to the effect of local or natural loads upon the stability of the structural elements during the process of structure erection. In this matter, moisture variation should be taken into account, because it could cause large shrinkage or expansions, support settlements, eccentricities or partial failures of connectors.

The following aspects require a special attention when referring to wood constructions:
- the elements have the tendency to deform under permanent and temporary service loads. In some cases, residual deformations could occur and a nonlinear calculus may be required;
- on long term, the environmental factors could cause loss of strength capacity as a result of contractions and apparition of cracks in elements;
- for light and pre-engineered buildings, the dead load to live load ratio is large, resulting a high sensitivity to live load variation and possibility of construction overturning or lifting off supports;
- service state design [8] can be controlled thru rigidity requirements in order to limit transversal deformations, lateral sliding and vibration transmission.

2. Samples of wrong design of connections with metallic connectors

In the context of the above, there are several types of connections [5] shown and explained in the sketches below. They represent connections which have generated issues and should be avoided in the future or remedial work should be applied if rehabilitation of wood structure is considered.

A sudden change of a cross section (carving) at the end of an element will create two problems. First is that the shear resistance of the element is reduced; the second is that exposing the end of grains by carving the wood, the moisture will faster penetrate the lower section of the element and a crack as shown in Figure 1 can occur. The problems shown in Figure 2 are similar with the ones in Figure 1, except that they are not as easy to observe.

In Figure 3 the clip angles and the bolts are attached to the upper section of the element. Similar to Figure 1, this type of connection reduces the shear capacity and increases crack development problem.

The beam shown in Figure 4 bears on a masonry wall and at the same time has the upper section bolted to the wall using clip angles or similar fasteners. For deep beams, the dry shrinkage
will reduce the depth and it could develop a crack at the top connection because the deformations at the bottom are restricted.

Incorrect positioning of the gusset plates at the end of the beams (see Figure 5, at upper section) can lead to a defective behavior of connection. If the screw holes are not provided to allow for displacement of the upper section at the end of the beam, negative moments can occur. In the case of a connection that has not been designed to resist such efforts, cracks are most likely to appear. Hanging heavy or moderate weights (see Figure 6) thru screws fastened to the area of the element having the grain in tension can produce cracks at the screw level.

Figure 7 shows how the upper section of a beam has been carved above an intermediate support in order to connect with another element on perpendicular direction. In the case of continuous beams, this procedure can lead to the apparition of cracks along the grain (longitudinal cracks) starting at carving location. There are cases when the base of columns or arches is buried in poured concrete as shown in Figures 8 and 9. if the concrete has direct contact with the grade, the moisture will migrate thru capillarity to the base of the wood element and it will cause degradation.

These situations can be improved by providing ventilation holes that will allow water evacuation and evaporation. Figure 10 shows a column with corbel. Fastening the gussets as shown in this figure, can lead to the crack development in the longitudinal direction of the column because
the screws are installed in the stressed area of both, the column and the corbel. The perpendicular efforts to the stressed grain will produce cracks which can lead to a sudden failure.

A very simple and very often used method of joining a secondary beam to a main beam is that of using clip angles as shown in Figure 11. Using bolts thru, the clip angles are fastened to the secondary beam over the full extent of its width. Having long and rigid clip angles in a connection where both beams will shrink, there is a possibility that splitting of the wood within the main beam can occur.

Figure 12 shows problems that occur during erection when the upper floor is affected by humidity. The expansion of the floor can develop horizontal loads which can lead to detachment of the secondary beam from the main one. The elements of a truss can be joined together by using metallic connectors. These are shop fabricated in one piece, providing constant angles between diagonal members and top and/or bottom chord. Once the truss is loaded and deformations occur, the angles between wood members will modify, but they are restricted by the rigid connectors. This situation can lead to wood splitting along the placement direction of the thru rods.

CONCLUSIONS

The necessity of connecting wood elements appears specially due the fact that wood selection for cross sections and lengths is limited. During design and erection of a wood structure consideration should be given to the fact that the overall structure has to provide strength capacity under all the loads applied to it. Poor positioning of connectors due to either, design or erection, as well as, using inappropriate connectors when joining wood elements, combined with shrinkage and/or expansion phenomenon and excessive loading, can produce cracks within the structural wood elements and jeopardize the safety of construction.
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