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THE INFLUENCE OF MASS LOSS ON WOODEN ELEMENTS CASE STUDY

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Abstract: The durability of wooden structures is a subject of great interest because a better understanding of the evolution of wooden elements is needed, together with the factors that intervene in the degradation process and the manner in which they can be prevented. The exposure time of structures to environmental variations is important because the presence of humidity is affecting wooden elements the most. Their exposure to humid surroundings or in which temperature and humidity variations are not constant, increases the moisture content of wood and leads to the formation of biological environments that attack the wood and reduce its resistance, intervening in the building safety and utility. The current study follows the evolution of a wooden structure subjected to changes of the transversal section due to the presence of humidity until the moment in which the wooden piece does not verify anymore the safety conditions from the calculations for compression, tension and bending.

Keywords: timber structure, cross section, temperature, humidity, moisture content, decay

1. Introduction

Wood as a hygroscopic material presents mechanical properties (rigidity and resistance) but also physical properties (water ductility) that make it a preferred material for constructions. Even though constructors have developed other materials such as concrete or metal, lately, wood has started being more and more used.

The resistance of wooden structures over the years depends on the effect of humidity that together with the variations of the environmental conditions deteriorate the material. The exposure time of the whole structure at high humidity and the moisture content of unprotected wood help the forming of moulds and fungi on the wooden piece until its final deterioration. [1] This means that wooden elements can have large quantities of water that are undesired and that together with temperature variations from zero up to high values can deteriorate wood composition and its properties (where the mass transfer is made) and can take in the end to the ageing of the building. [2]

In the construction industry, the planning and the performance of the life expectancy of a structure has to be taken into account from the beginning. This is why mass loss models have been created and used because they can predict the good development of a building if they work in a correct manner. However, although the models are good, they cannot always be allocated to wood because of its organic nature. Since a few years, researchers have been studying the development of fungi and moulds and their impact on wood. The studies have been based on different strategies and on wooden variables such as: mass and resistance loss, disintegration marks and lifetime. The models are called performance models and the most important fact in their correct realisation is the definition of the data for the variables used in the study. Reliable climate models have to be made in order to show how relative humidity, temperature, wind direction and precipitation characterise the climate hazard of a certain location. From an engineering point of view, this degradation does not represent a great part of the final function of the structure because what counts exactly is the formation of cracks, aging and corrosion of the metal articulations. [3]

The study made by [4] is also based on wood modification because of the constant changes of the environmental conditions; this can make wood stronger or it can deteriorate it permanently due to the decomposition of hemicellulose. When temperatures are higher, wood components are less stable. However, if the temperature is just slightly modified, wood resistance in compression is increasing. When the moisture content presents a growth in its value, induced humidity and forces of transversal tension in the inferior part of the transversal section appear.

2. Mass loss of wood

The study [5] is based on a deterministic model of degradation created to follow the evolution of a wooden piece in a certain period of time by successive recordings of temperature and humidity from a beforehand established environment for a period of 15 years. The program of deterioration created in the mentioned study, can be applied on any type of wood, for any wood species, if its characteristics are known before. Through this study, the necessity of enlargement of the cross section of the wooden piece for certain regions in which the conditions of humidity and temperature have a great influence on its evolution is taken into consideration. Nevertheless, the theoretically created models need an examination with real data and with experiments made in-situ on different types of wood submitted to various environmental conditions in order to create a controlled model of wood deterioration. This is why in the current study a detailed numerical model is made in order to follow the evolution of the structural system from an engineering point of view.

When talking about the studies and the research made by [6] and [7] some equations have been developed for the realisation of the empirical model for the mass loss of wood. The following equation has been created in order to show the increase of degradation made by the brown root in the sapwood of pine, in constant conditions. The decay model created is divided in two parts: the activation process and the mass loss process, which follow different parameters that are part of a decay model.

$$\frac{ML(RH(i),T(i))}{dt} = -5.96 * 10^{-2} + 1.96 * 10^{-4}T(i) + 6.25 * 10^{-4}RH(i) \text{ [\%loss/hour]} \quad (1)$$

where:

ML- represents the mass loss in % from the initial mass of the wooden piece;

t - represents the time expressed in months;

T - represents the temperature in °C;

RH - represents the relative humidity of the air in %.

This model expressed as mass loss is applicable only if $T \geq 0$ °C and $RH \geq 95\%$. The model shows growths of degradation for a constant temperature of 15°C. [7]

The mechanical and physical properties of wood as construction material that is part of a structure can be changed due to a combination between the loads that are applied on it and the quantity of humidity, temperature and biological activity. In the calculations, these changes are taken into account and introduced through different coefficients that are related to the material, to the structural dimensions and to the charges that are applied on the structure. These coefficients are applied in the calculation in order to ensure the structural safety and they depend on the classes that the structures are found in. Even more, structural durability in long term depends on the humidity effects that in a combination with temperature variations and with the time of exposure can deteriorate the resistance capacity of the material. The exposure of unprotected wooden structures to humid environments increases the moisture content of the wood and takes it to fungal degradation. This deterioration mechanism reduces the resistance capacity of wooden structures by affecting its utility and safety. [8]

Researchers have demonstrated that wood resistance decreases when humidity varies between 25-30% and after this value it does not influence the resistance in an important manner. However, this can be seen more for compression than for tension. When talking about the temperature, the process is the same if the temperature is rising, the resistance of wood decreases. For example for temperature of 25°C to 50°C, tension resistance decreases with 15-20% and compression resistance with 20-40%. [9]

3. Case study

The degradation models are based on measurements made in-situ or in the laboratory for different locations and species of wood. Wood degradation is evaluated in the degradation model presented in article [5] that is concentrated mainly on the specific conditions of certain environmental conditions chosen beforehand and estimates a value of the mass loss over time. The methods used for the calculation have to take into account the material properties (each wood species has its own characteristics) the loading mode on the material, the duration of the application of charges (permanent or of short duration), the temperature and humidity variations according to the environment in which the construction will be made.

For the demonstration of the mass loss of wood when it is exposed to external factors that modify its physical and mechanical properties, a model of a wooden truss has been created. The analysis has been made in the Structural Software for Building Analysis and Design- Etabs. The values of the elements of the structure for the bottom chord (checked for tension) and for top chord (checked for compression) are 15x15 and 15x19 cm respectively for elements made from a regular, solid, untreated wood. Also, a beam with a length l=4m on which a permanent load and snow is applied is verified in bending and deflection.

When calculating the structure, standards for wind and snow are used for the determination of the charges that act on the structure (0,2 kN/m for the permanent charge and 2kN/m for snow) found in Bucharest and for the verification of the elements are used the Eurocode 5 and the Romanian standard NP 005. Finally, the mass loss process generated by the deterioration process is applied on the elements. The climate for the Bucharest area is continental, specifically for Romania, and the winter-summer temperature differences are up to 50 °C.

Afterwards, a model of mass loss previously created in [4] following the mass loss process mentioned above that depends on specific environmental conditions for the two sections and the evolution of the wooden material over a period of 15 years can be seen (Fig.1).

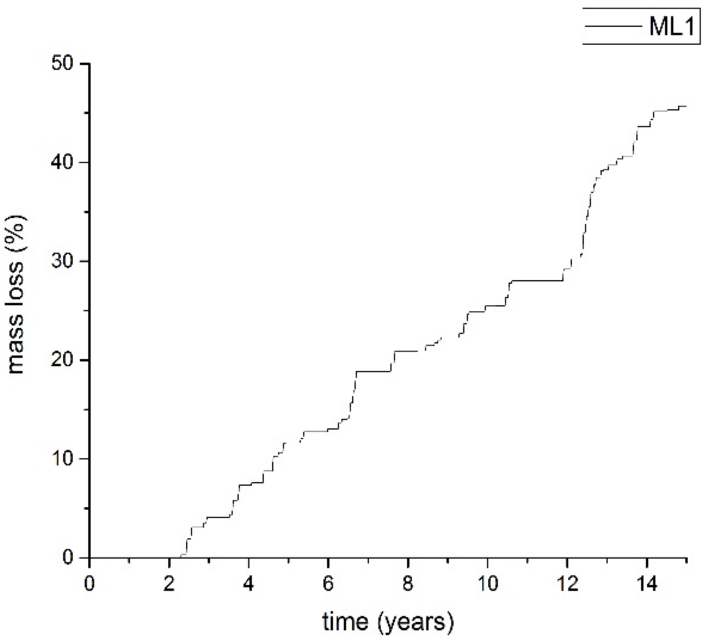

Fig. 1 - The representation of the mass loss process for a certain climate with variations of temperature and relative humidity on a period of 15 years. Graph generated in [4]

In the calculus, partial safety coefficients are used, that are different according to the humidity conditions m_T, m_u and k_{mod}. For example, for untreated wood $m_T = 1.0$, $m_u = 0.9$ (for tension), $m_u = 0.95$ (for compression) and $k_{mod} = 0.90$ (for solid wood and for a long-term action) for all situations- values taken from the standards. It can be observed that slowly the wooden structure starts deteriorating when the mass loss starts growing. The main principle is to find the right moment when the stress from the section does not validate anymore the condition of verification. From that moment on, the wooden piece does not perform at its maximum capacity for which it has been calculated and can give up at any moment.

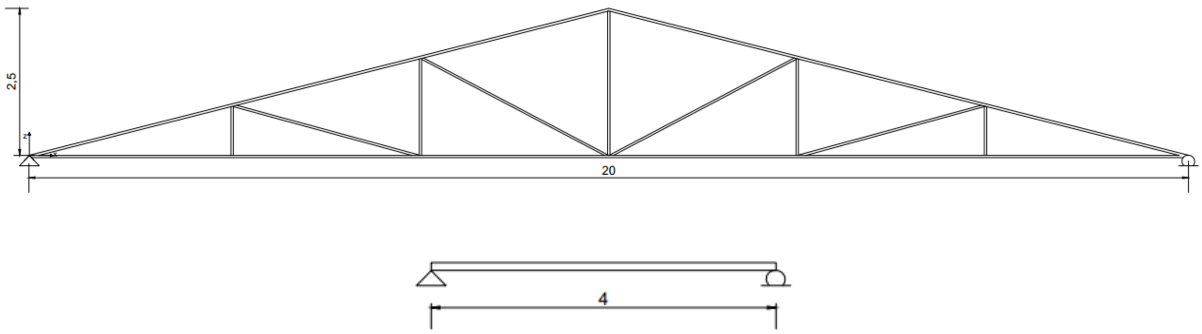

Fig. 2 - Graphical representation of the wooden truss and the wooden beam used in this study

The calculations are based on five cases of degradation of the wooden pieces that can be found in real situations in order to see which is the most unfavourable pattern of degradation. The case IV is the most unfavourable case from a deterioration of the section point of view because it represents the shrinkage of it on all sides, a case that is rare seen in reality, possible only if the interior part of the element is subjected to temperature and humidity variation.

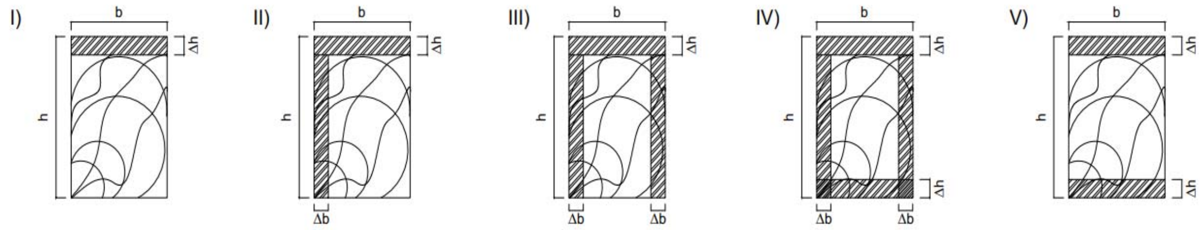

Fig. 3 - The five cases for the degradation of the wooden pieces used in the study where the hachured part represents the degradation

The idea follows the degradation model mentioned above using a generation of the mass loss process for a general climate depending on temperature and relative humidity changes. This mass loss model is then applied to the wooden pieces considered in the study, already calculated as part of the truss.

The calculations based on the degradation model set for a determined period of time of 15 years follow a real simulation of a climate based on real data of temperature and relative humidity where the mass loss goes up to almost 50%.

The areas of the cross sections are calculated for the two elements of 15x15 cm and 15x19 cm for all the degradations sections presented above (the five cases presented in the study) on which the mass loss process has been applied. The time considered for the study is 15 years for a mass loss of 50 % and on the graphics below (Fig. 4) it can be observed that the area of the section decreases depending on the mass loss.

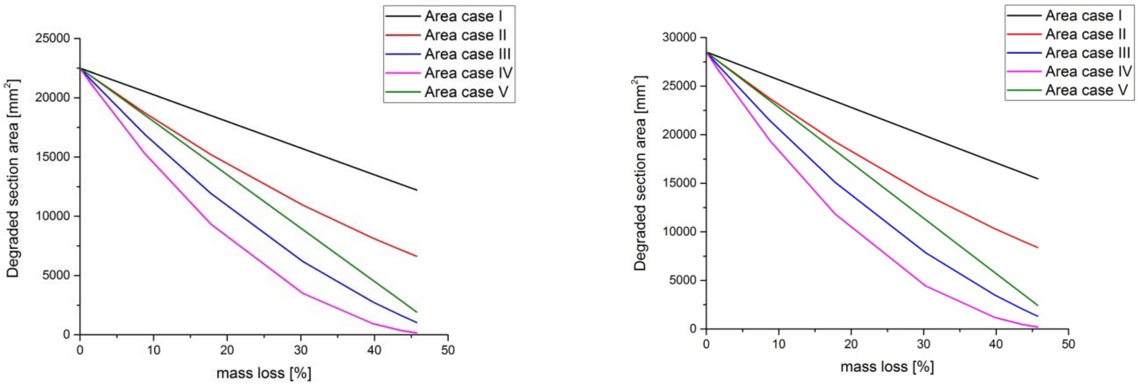

Fig. 4 - Graphic representation of the aria evolution of the cross section for each case of degradation for section 15x15 (first graph) and 15x19 (second graph)

3.1 Calculation for the solicitation in tension (15x15 cm)

When talking about the solicitation in tension of the wooden piece, the values of the calculation after the two standards, Eurocode 5 and NP 005-03, are different. For case I, the values of the resistance capacity for the solicitation in tension following the two standards are mostly the same and the mass loss of 30% (EC) and 33% (NP) does not permit the verification of the section after 12 years according to the process of mass loss applied on the wooden pieces. For the II and III cases, the values of the calculations are similar and the mass loss of 10% respectively 20% is decreasing the resistance time for a period of 6 years. The case IV is the most unfavourable case from a deterioration of the section point of view because it presents shrinkage on all sides, a case that is rare seen in reality, possible only if the interior part of the element is subject to temperature and humidity variation; the element arrives in 2 years at a mass loss of 8,7%. For case V the values for the mass loss are the same for the two standards 17,8% where the degradation can appear in 5 years.

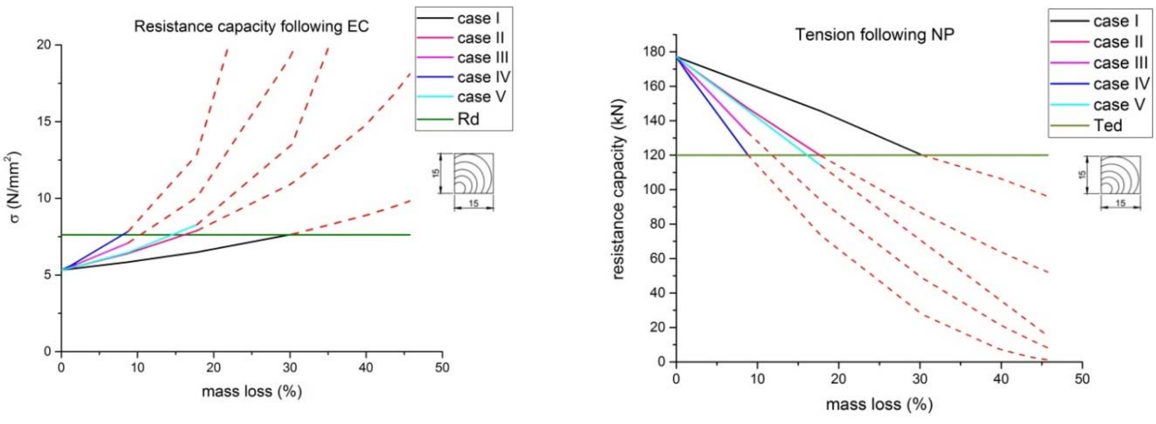

Fig. 5 - The representation of the calculation following the two standards used, EC and NP in the five cases of degradation for the wooden piece of 15x15 cm; the tension resistance capacity σ is in N/mm^2 and the resistance capacity following NP is in kN

The graphics represent the resistance capacity for the tension solicitation in kN of the wooden piece of 15x15 for all five cases of mass loss, following EC and NP, Rd representing the design tensile strength along the grain and Ted the effort generated by the calculus program ETABS for the current structure. On the graphic it can be observed the moment in which the wooden piece cannot be used at its maximum capacity for which it has been calculated, being able to give up at any time and also the time when the design effort is encountered in each case. The most favourable case is the Ist one where the maximum effort is seen up to a mass loss of approximately 30% in a period of 12 years. The worst case scenario is case IV where the maximum effort is seen for a mass loss of 8% in a period of 2 years.

3.2 Calculation for the solicitation in compression (15x19 cm)

For the compression solicitation, the wooden piece has the dimensions 15x19 cm. For the calculation of the structure, the two standards Eurocode 5 and NP005 have been used like in the previous one for the tension solicitation. The results are presented below.

For the Ist case the resistance for the solicitation in compression of the wooden piece of 15x19 is verified following EC for all 15 years considered in the degradation model whereas following NP, the wooden piece can break after 10 years for a mass loss of 30%. For the second case the verification is almost the same as for the first case for EC, the piece arriving at a mass loss of 40% in a period of 13 years, but for NP the mass loss arrives at 8,33% after 2 years of exposure.

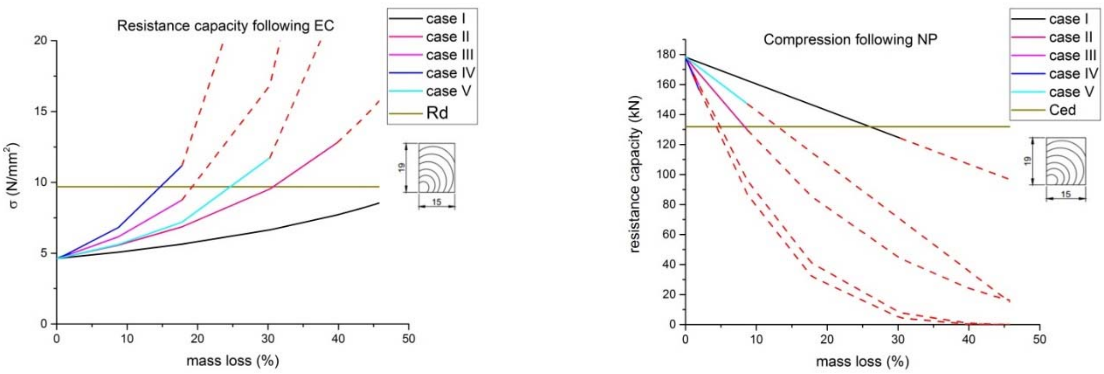

Fig. 6 - The representation of the calculation for the compression resistance following the two standards used EC and NP in the five cases of degradation for the wooden piece of 15x19 cm; the compression resistance capacity σ is in N/mm^2 and the resistance capacity following NP is in kN

The graphics represent the resistance capacity in compression of the wooden sections of 15x19 cm in which the moment, represented by the dotted red line, when the verification of the section does not take place anymore and the wooden piece cannot be used at the maximum capacity for which it has been calculated. The cases are analysed following the two standards used, Eurocode 5 and Romanian NP 005. *Rd* represents the design compression strength along the grain and C_{ed} the effort generated by the calculus program ETABS for the current structure.

The graphics present a comparison between the values of the resistance in compression on each case following the two standards, the red line signifying the moment in which the verification of the wooden piece is not accomplished anymore which means that the wooden piece can crumble at any moment. The first case is the most favourable because the wooden piece has a good resistance even though the mass loss can arrive at 40% for the EC standard and at approximately 30% for the NP standard. The IVth case being the most unfavourable one shows that the wooden piece arrives at a mass loss of approximately 20% in 7 years for the EC standard compared with 4% in 1 year for the NP one.

3.3 Calculation for the solicitation in bending and deflection (15x15 cm and 15x19 cm)

When talking about the bending strength, the two sections of the wooden piece have been analysed following the two standards as in the previous calculations. The comparison is made step by step between the two of them because the cross section is the main factor in a better resistance in bending. In all cases, the deflection of the beam for every section (15x15 and 15x19) follows the same deterioration pattern. However, the differences between the two standards can be seen visible on the graphs.

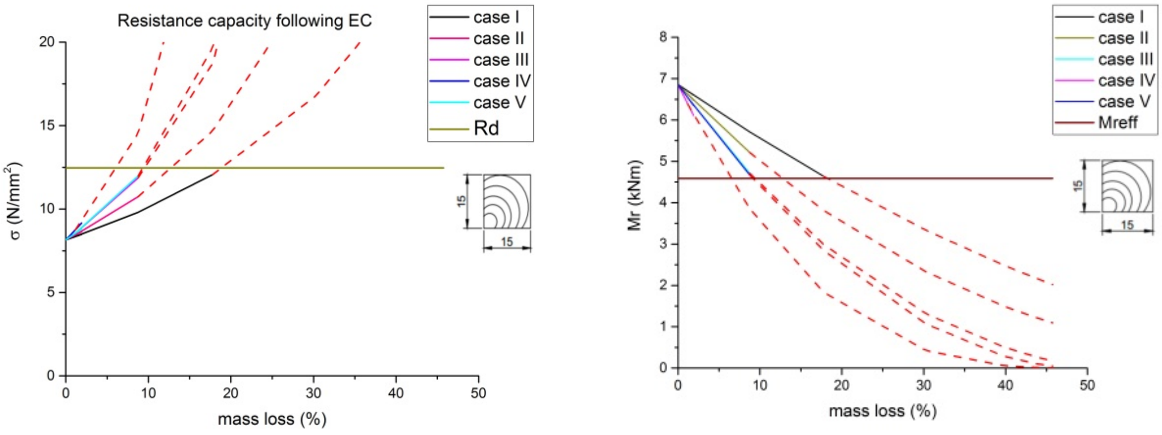

Fig. 7 - The representation of the resistance capacity σ following the EC standard and Mr the resistance capacity in bending for each of the five cases for the section 15x15 cm

Following the graphics it can be seen that the values for σ and *Mr* for the cases II, III and V are going in a parallel direction for the two standards used: mass loss of 17,8% in 6 years compared with the design values for each standard where *Rd* represents the design bending strength along the grain and M_{reff} is based on the effort generated by the calculus program. For the IVth case, the most improbable one, the values are also the same following the two standards and the wooden pieces can arrive to a mass loss of 6,5% in 1,5 years.

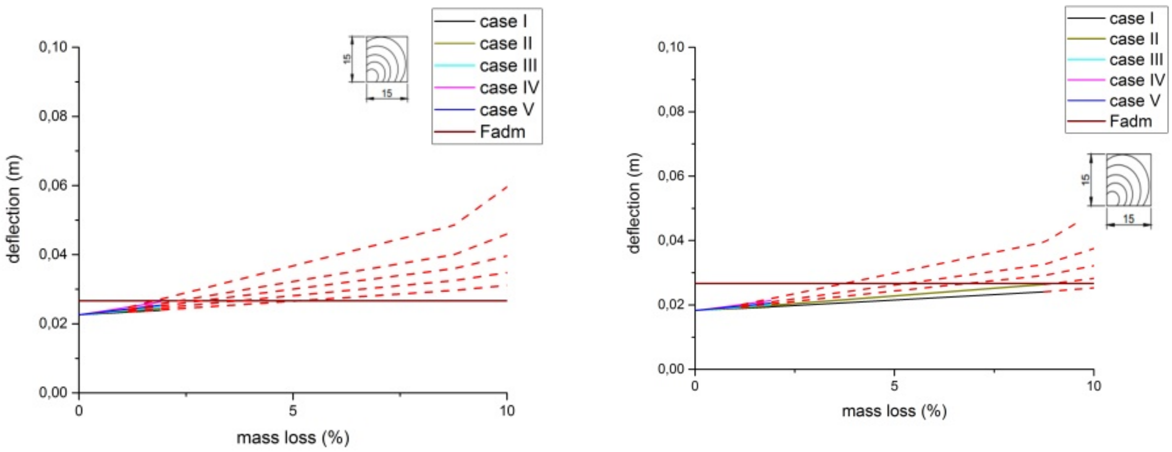

Fig. 8 - The representation of the deflection of all cases of degradation following the two standards considered, EC (first graph) and NP (second graph) for the section of 15x15 cm

Following the graphics it can be seen that the deflection for the cases II, III and V are also going in a parallel direction for the two standards used, the lowest value being for the EC standard for a mass loss of 3,5% in one year (or 0,5 years for the case V) compared with the 2 years that the deflection can resist for the NP. For the IVth case, the most improbable one, the values are also the same following the two standards and the wooden pieces can arrive to a mass loss of approximately 1,5% in 0,5 years.

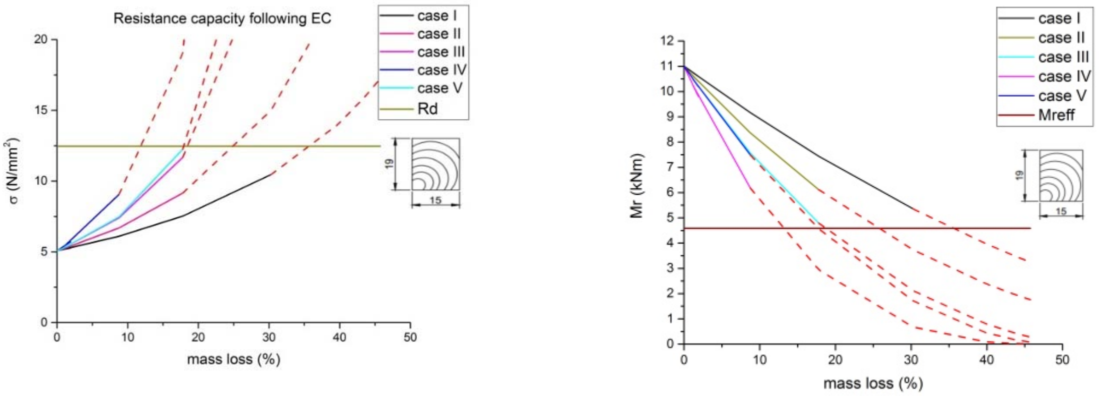

Fig. 9 - The representation of the resistance capacity σ following the EC standard and Mr the resistance capacity in bending for each of the five cases for section 15x19 cm

From the graphics it can be seen that the first case is the most favourable one in terms of degradation. For the EC standard, the value for the resistance arrives at a mass loss of 30% in 12 years compared with the NP standard where the values are approximately the same. For the IVth case for EC the values go up to 8 years for a mass loss of almost 9% and for NP the values go up to 9 years for a mass loss of 13%.

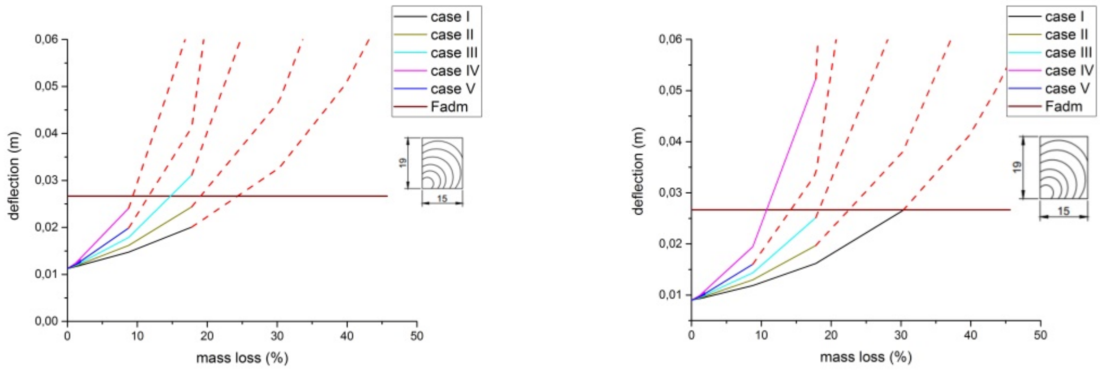

Fig. 10 - The representation of the deflection from all cases of degradation following the two standards considered, EC (first graph) and NP (second graph) for the section of 15x19 cm

When analysing the deflection for the section 15x19 cm following the two standards used, the values are almost the same 17,8% mass loss for a period of 2 years. However, for the EC standard the resistance is lower, almost 20% mass loss for the first case scenario and 10% for case IV, compared with the NP standard where it can arrive at a mass loss of 30% for the first case and 15% for case IV.

4. Conclusions

Wooden roofs are the most appropriate structures to be used for this study because they are the most exposed to climatic changes and to high humidity and this can cause fungus and micro-organisms attacks. Following the calculations and the analyses made, it has been observed that after the reduction of the cross section of the wooden piece used in this model, the verification of the section does not take place anymore and the wooden piece can give up at any time because its maximum potential from the calculation is not reached anymore. The differences can also be observed in the calculations of the two sections following Eurocode 5 [10] and the Romanian standard NP 005 [11] because of the coefficients that appear in the calculation. From the graphics it can also be seen the moment after which the mass loss starts affecting the wooden elements and the sections cannot verify anymore the condition of validation of the calculus for tension, compression and bending. The wooden piece can still be used but it can crumble at any time.

From the calculation it can be seen that following the Eurocode 5 standard, less material is used because the verification of the sections permits that and economically speaking this is a better approach. However, even though this is an important factor in the realisation of wooden constructions, the estimated time for the use of such an element is important too and should be more analysed.

The differences that appear for the three types of load in compression, tension and bending following the two standards used, appear because of the coefficients that intervene in the calculation. Following Eurocode 5, the modification factor k_{mod} includes in its value the effect of the charge duration and of the humidity whereas for the Romanian standard NP 005, in the calculus, the treatment of wooden elements is taken into account (from treated wood up to fireproof one) and the working conditions that intervene in the process that insert the presence of humidity of the wooden material and the duration of the action of charges (m_T, m_{ui}, m_{di}). From these differences of the coefficients that intervene in the calculus following the two standards, the resistance values according to the EC are higher than the ones after NP.

The conclusions of the study are a good step in the demonstration of the fact that the mass loss due to changes in the climatic conditions (temperature and humidity) influences the evolution in time of the untreated wooden elements. They show the moment in which the wooden piece can crumble at any time and for this reason it cannot be used anymore in safe conditions. The results of the study can change according to the environment because of sudden changes of temperature and humidity but also because of the wooden species used, because the properties of the materials are different for each wood specie.

However, the two standards used in this study do not give a lot of information on the influence of temperature and humidity on timber elements and perhaps this should be an important detail when calculating the elements for structures.

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