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Advances on structural design with timber in Uruguay: towards a proposal for a National Annex to Eurocode 5

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Abstract

In Uruguay there is not a national document for design specifications for timber construction, so engineers and architects must employ foreign codes based on the available formats, i.e. Load Resistance Factor Design (LRFD), or Allowable Stress Design (ASD). Some codes, such as the dual format NDS 2012 edition, allow the designer to select the calculation method. Usually, this selection involves information about material properties, such as characteristic or mean values, and the methodology to determine those values. In such context, seems to be appropriate the adoption of an existing code for Uruguay, and the development of specific Annex containing information regarding locally wood materials, adjustment factors, etc. After the analysis of various foreign codes, the European Standard Eurocode 5 was selected. To adopt this code, a Uruguayan National Annex (NA) to Eurocode 5 (EC-5), part 1-1 and part 1-2, is proposed and presented in this work. The proposed Uruguayan NA to EC-5 contains information about Nationally Determined Parameters (NDP), as load duration classes, service classes, local partial factors for materials depending on accepted risk level in buildings, deflection limit values and partial factor for material properties under fire, among others. Furthermore, this NA contains Non-contradictory Complementary Information regarding to the relationship between Uruguayan and European Standards about actions in structures, load combinations, limits for fire resistance, etc.

Key words: Timber structures, Design Codes, Eurocode 5, National Annex, Nationally Determined Parameters, Non-contradictory Complementary Information, Uruguay

1. Introduction

The Uruguayan forestry sector has had a significant increase in wood volume during the last thirty years as a result of a government policy to promote forest plantations. In the 80´s, according to estimations by the General National Boureau of Forestry (*Dirección General Forestal, DNI)* of the Ministry of Agriculture, Cattle and Fishery (*Ministerio de Ganadería Agricultura y Pesca*, *MGAP*), there were between 120,000 and 137,000 hectares of cultivated species. Currently, forest plantations cover close to 1 million hectares of fast-growing exotic species, mainly pine (*Pinus* sp.) and eucalyptus (*Eucalyptus* sp. The main industrial use of eucalyptus species is the production of pulp, while the pine and part of the eucalyptus (*Eucalyptus grandis*) are used for construction products (Dieste 2012). The main products are eucalyptus logs, plywood (eucalyptus and pine) and glued laminated timber (*E. grandis*). 1.7 million m^3 of pine logs (mainly *P. elliottii* and *P. taeda*) and 0.4 million m^3 of eucalyptus (mainly *E. grandis*) have no current industrial destination (Dieste 2014). The Uruguayan government has proposed the incorporation of timber for structural use, which implies the need for a national system of standards for timber products and the development of codes and rules for design and construction with timber.

The design process of any structure mainly involves three aspects: i) characterization of the mechanical properties of the materials (steel, timber, concrete, etc.); ii) definition of loads and load combinations applied to the structures; and iii) the definition of the safety requirements of the structure. The definition of these aspects depends on the structural design philosophy employed: Allowable Stress or Limit States. Internationally, both approaches co-exist, but the trend is towards the replacement of the first method by the second one.

In the United States, the method of the Allowable Stress, known by its acronym ASD (Allowable Stress Design), has been gradually replaced by the method of Limit States, commonly called LRFD (Load and Resistance Factor Design). It was introduced in the 70's for reinforced concrete (ACI 318 1970), in 1986 for steel structures (AISC 360 1986) and in 2005 for wood construction (NDS 2005). The most recent editions of the United States timber constructions code propose both approaches for timber and steel. Argentina and Chile have their own timber code, CIRSOC 601 (CIRSOC 601 2013) and NCh 1198 (NCh 1198 2006), respectively, which employ the ASD method, while Brazil (NBR 7190, 1997 and NBR 7190 2010) and the European Community (Eurocode 5: EN 1995-1-1 2004/AC:2006 and EN 1995-1-2, 2004/AC:2009), adopted the LRFD method.

The Eurocodes are a set of European rules aimed at removing the technical barriers to trade and the harmonization of the technical specifications in the areas of design, calculation and sizing of structures, developed by the European Committee for Standardization (CEN). These generic documents are adapted to local conditions in each country through the National Annexes to the Eurocodes. They are technical documents of national implementation whose objective is the definition of the Nationally Determined Parameters (NDP) and, optionally, Non-contradictory Complementary Information (NCCI) to Eurocodes.

In Uruguay, the Uruguayan Institute of Technical Standards (UNIT) regulates the national standards. UNIT 33:1991 (UNIT 33 1991) and UNIT 50:1984 (UNIT 50 1984) regulate the actions on structures; the first is related to self-weight and imposed loads for buildings and the second to wind actions. However these standards are not up to date. UNIT 33:1991 does not provide accidental actions (e.g. impacts, fire, etc.), earth or water pressure and actions on other structures, such as bridges or silos. UNIT 50:1984 does not include aspects such as dynamic and aeroelastic effects or design of structures different than buildings. There is a standard for reinforced and mass concrete (UNIT 1050 2005), based on the old Spanish Instruction (EH-91 1991), which uses the LRFD method for the design. However, it does not include the design of prestressed concrete structures and the design in case of fire or the variability of the partial factors depending on the action, among others. There is not a UNIT standard for steel and timber structures. However, there are two documents that define structural design criteria for both materials, IE3-53 (IE3, 1953) and IE4-50 (IE4, 1950) respectively. They were elaborated by the Institute of Structures and Transport, Faculty of Engineering, Universidad de la República, in the 50´s and both of them are based on the ASD method. IE4-50 includes bending strength allowable values of different wood species.

Therefore, in Uruguay there is no a national code for the design of timber structures, which includes from the characterization of materials and manufacturing specifications of engineered wood products to the design, calculation and building construction. This could cause inconsistencies between the mechanical properties of the material and the design code used for engineers or architects, besides the uncertainties in the reduction factors to be applied to the mechanical properties. Also, there is not a common criterion for all materials regarding deflection limits of structural elements, acceptable vibration frequencies depending on the use or time required of mechanical resistance in fire situation of the elements for different uses, among others.

The objective of the this paper, therefore, is to present a proposal to of the National Annex to Eurocode 5 (Part 1-1 and Part 1-2) that includes the Nationally Determined Parameters and Non-contradictory Complementary Information that assist the implementation and interpretation of the Eurocode 5 in Uruguay.

2. Methodology

The results of this paper were obtained under the research project entitled "Technical Documents for standardization of timber structures and buildings", funded by the National Direction of Industry (*Dirección Nacional de Industrias, DNI*) of the Ministry of Agriculture, Cattle and Fishery (*Ministerio de Ganadería Agricultura y Pesca, MGAP*). The project included two lines of work: i) determining the physical and mechanical properties of timber in Uruguay and ii) design a code for timber structures, being the results of this second line presented in this paper. The tasks performed in the project are described below.

2.1. Analysis of international Codes for the design of timber structures

Workshops and technical seminars, with participants from Argentina, Brazil, Chile and Spain, were made with the aim of sharing experiences in the process of development the codes for the design of timber structures. The reasons that influenced the choice of the format of calculation in each country and the most important aspects of the process of developing of the codes were discussed. Topics included: i) characterization of sawn timber and visual grading; ii) background about characterization of timber and design codes in Uruguay; iii) minimum production requirements and quality control for glued laminated timber (glulam); iv) serviceability limit states: limiting values for deflections of beams and vibrations in residential floors; v) structural fire design; vi) analysis of the wind standard UNIT 50-84 and relationship with Eurocodes; and vii) analysis of the different codes for the design of timber structures.

2.2. Development of the Uruguayan Code for the design of timber structures

The considerations taken into account in the proposal for the Uruguayan Code for the design of timber structures were, among others, coordinating requirements with other structural materials, with the standards of actions on structures and testing and grading of timber, taking into account existing international standards.

2.3. Adoption of an existing Code

An existing Code for the design of timber structures (Eurocode 5) was adopted instead of generating an own Code and the corresponding European Standards (EN) for the characterization of timber, testing, processing requirements for the engineered wood products, etc. The use of the EN presents several advantages for Uruguay, such as consistency between the material characterization and the design code, regular updates, internationally recognized and save much work for generating own standards and codes, already developed.

The proposal for the National Annexes to Eurocode 5 for buildings (EN 1995-1-1 2004 and EN 1995-1-2 2004) were developed. EN related to the characterization of sawn timber and glulam (prEN 408 2015; prEN 384 2014; prEN 338 2012; EN 14080 2013, etc.) were adopted to obtain values of the physical and mechanical properties of national wood.

2.4. Drafting of a proposal for the Uruguayan National Annex to Eurocode 5

A proposal for the National Annex to Eurocode 5, in the part 1-1 related to common rules for building and in the part 1-2 of design in case of fire, is drafted for Uruguay. Spanish National Annex (AN_UNE EN 1995-1-1 2014 and AN_UNE EN 1995-1-2 2014) and British National Annex (BS NA EN 1995-1-1 2008) are considered as background. Uruguayan National Annexes include the Nationally Determined Parameters (NDP) and Non-contradictory Complementary Information (NCCI) to the Eurocode 5 for the design of timber structures in Uruguay.

3. Results and Discussion

3.1. Uruguayan National Annex to Eurocode 5: Part 1-1

The proposal of the National Annex intends to define the conditions of implementation in Uruguay of the Eurocode 5 and, in case of not having enough information, define the necessary lines of research. NDP and NCCI are defined for Uruguay.

3.1.1. Nationally Determined Parameters

3.1.1.1. Load Duration classes and Service Classes

Eurocode 5 enables the assignment of classes of duration to the loads and the service classes to the structures. In both cases the classes defined in the Spanish National Annex were proposed with minor modifications, such as the assignation of the wood used for formwork to Service Class 3.

3.1.1.2. Design values of the material properties

Timber in Uruguay is not graded or structurally certified and there is not experience in timber construction, so other design values of the material properties (Table 1) than the ones proposed by Eurocode 5 are suggested. The values were defined as a function of the quality control of timber and of the quality control of the construction process in order to obtain the same probabilities of failure of the structures. They were obtained from the recommendations presented on the Eurocode 0 in its Annex 3 (EN 1990 2002) and the mechanical properties of about 200 specimens of Uruguayan *Pinus elliottii/taeda*.

Table 1: Proposal of the design values of the material properties in Uruguay

Quality control of the timber	Quality control of the construction	Design value of the timber properties
Normal	Normal	1,60
	Intense	1,45
Intense	Normal	1,45
	Intense	1,30

3.1.1.3. Serviceability Limit States: limiting values for defections of beams, horizontal displacement and limit values for the vibrations in floors

Limit values for deflections of beams and for horizontal displacement of the structure and limit values for the vibrations of floors were included as an alternative to the proposed values presented in the Eurocode 5. They are taken of the Spanish National Annex to Eurocode 5 and from the Spanish Technical Building Code - Basic Document - Structural Safety: Timber (CTE-DB-SE:M 2009). Three criteria are considered for the limiting values of deflections of beams: a) integrity of the construction components; b) the user comfort and c) the appearance of the structure. The limits for the active deflection in the case a) varies between l/200 and l/500; the limit of the instantaneous deflection for the case b) is l/350 and the limit of the final deflection for the case c) is l/300.

3.1.2. Non-Contradictory Complementary Information

3.1.2.1. Relationship between the UNIT Actions Standards and the Actions on Structures of the Eurocode 1

The use of the standard UNIT 33 (UNIT 33 1991) is presented as an alternative to Eurocode 1 about self-weight and imposed loads for buildings (EN 1991-1-1 2002). The use of the standard UNIT 50 (UNIT 50 1984), about wind on structures, is recommended to determine the characteristic wind velocity (v_k) and use one of the following methods: i) to convert the characteristic wind velocity (v_k) defined by UNIT 50 in the basic velocity defined by Eurocode 1 (v_b) and define the wind actions on the structure according to Eurocode 1 or; ii) to define the wind actions on the structures according to UNIT 50. Equation 1 is used to convert v_k to v_b (Páez and Morquio 2014), where the coefficients define the orography, the sampling interval and the return period.

$$v_b = 0{,}858 \cdot 0{,}676 \cdot 1{,}149 \cdot v_k = 0{,}667 \cdot v_k \tag{1}$$

3.1.2.2. Other parameters

Based on Eurocode 0 and the Spanish Technical Building Code - Basic Document - Structural Safety (CTE-DB-SE 2009), the actions on structures and actions combinations were defined. Regarding the definitions for the calculation of the Serviceability Limit States, active, instantaneous and final deflections of beams are defined, as well as the active and final horizontal displacement of a building and the procedure for the verification vibrations on floors. Other parameters were taken from the recommendations of the Eurocode 5 and the Spanish Technical Building Code because in Uruguay does not exist specific information about these topics. The need for research on the sensitivity to splitting of the *Pinus taeda*, *Pinus elliottii* and *Eucalyptus grandis* from Uruguay is highlighted.

3.2. Uruguayan National Annex to Eurocode 5: Part 1-2

3.2.1. Nationally Determined Parameters

Due to in Uruguay does not exist information about the mechanical resistance in fire situation the recommended values by Eurocode 5, part 1-2 are adopted. The partial factor for material properties ($\gamma_{M,fi}$) takes a value equal to 1.0 and the reduction factor for combination of actions (η_{fi}) takes a value of 0.6, except for storage areas where η_{fi}=0,7. Reduced cross-section method and reduced properties method for the procedure design of mechanical resistance in case of fire are admitted.

3.2.2. Non-contradictory Complementary Information

3.2.2.1. Mechanical resistance in fire situation of the main members of a structure

Due to fact that Uruguay does not have a regulation for resistance of structural members in fire situation, the values of R were adopted from Spanish Technical Building Code - Basic Document – Security in case of fire (CTE-DB-SI 2009).

4. Summary and Conclusions

Eurocode 5 part 1-1 (General rules for building projects) and part 1-2 (Timber structures in fire situation) was proposed to be used in Uruguay for the design of timber structures, after the workshop held with the participants in the development of structural codes for the design of timber structures in Brazil, Argentina, Chile and Spain. The adoption of the Eurocode for the design of timber structures in Uruguay establishes a precedent for the design codes to be followed in Uruguay for other construction materials.

A National Annex to Eurocode 5 was proposed. It contains the Nationally Determined Parameters and containing Non-contradictory Complementary Information to Eurocode 5 for the Uruguayan conditions of timber design.

NDP for Uruguay are, among others, the definition of load duration classes and service classes, also the assigning of design values of the material properties for the Uruguayan conditions and the limiting values for the serviceability limit states. NCCI contemplates the relationship between the UNIT standard and Eurocode 1 for wind on structures, a summary of the loads combinations according to Eurocode 0, 1 and 5 and the definitions of deflections on beams, horizontal displacement on buildings and limit values for vibrations on floors.

The following topics are recommended to be researched in order to complete the National Annex to Eurocode 5 with information about the local cultivated species (*Pinus taeda, Pinus elliottii* and *Eucalyptus grandis)*and local conditions: i) study of the design values of the material properties; ii) determination of the sensitivity to splitting*;* iii) study of the embedment strength; iv) study of the charring rates; v) determination of the physical and mechanical properties of sawn timber and engineered wood products from Uruguay and vi) development of an UNIT standard for visual grading and establish the correlation with the strength classes according to EN 338 to that refers the Eurocode 5.

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