The instructions for the design, execution and control of timber construction (CNR-DT 206 R1/2018)

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Keywords: Design, execution and control of timber constructions; CNR instructions, CNR - DT 206-R1

ABSTRACT

In 2007 the National Research Council published the technical document DT 206/2007 "Instructions for the design, execution and control of timber structures", with the purpose to provide a technical support to the operators of the sector, in line with the most advanced knowledge at that time. Since then, the world of timber engineering has largely used such document, even though the instructions are not mandatory standard rules, so that they became the most common tool in Italy for the structural use of timber, opening the markets and favoring competition and new applications. In latest years new studies, researches and innovative proposals have promoted the development and the growth of timber constructions also in the civil residential field. The framework of standard rules for constructions and products, both Europeans and Italians, has evolved too. For these reasons, CNR has considered as opportune to proceed to the editing of a new version, updated and widen, namely with the acronym DT 206-R1. The document comes from the spontaneous cooperation of an open group of specialists and operators of the sector, based on a wide discussion on the common scientific and technical expertise and knowledge. The current version has already taken into account the results of the public inquiry phase (concluded by now).

The paper presents the main contents of the document, evidencing the innovations.

1 INTRODUCTION

The field of timber structures is strongly developed all over the world in the last decade. In fact, thanks to easiness and quickness of construction, transportation, sustainability, energy efficiency and good seismic response they have become a valid alternative with respect to traditional materials.

A significant increase of the use of timber-based structures has been recorded not only in North Europe, which represents the typical area devoted to the use of timber systems, but also in the countries of Mediterranean area, like in Italy. In fact, according to Federlegno Arredo (2018), the timber building stock was estimated in Italy as a percentage of 7.0% of the overall market of residential buildings, percentage destined to grow in the coming years.

The technological progress in the case of timber structures is not immediately accompanied by an updating of design standards. In this light, at European level a revision of the Eurocode 8 (chapter 8), regarding the seismic design of timber buildings is recently started and it is quite to the conclusion (Follesa et al., 2018). Parallel to this, in Italy a review process of the Technical Document

DT 206/2007 "Instructions for the design, execution and control of timber structures" is started in 2015 and concluded in 2018. This document, issued for the first time by the National Research Council in 2007, was considered in the last years the main Italian technical support for practitioners and researchers operating in the field of timber structures, in line with the most advanced knowledge at that time as well as with the Europeans standards. Due to the new advancements in research, industrial development and practical applications, a significant modification of the document with respect to the original version is applied.

The new revised and widen version, namely with the acronym DT 206-R1, collects the most important experimental and theoretical research advancements on the behaviour of timber elements, sub-assemblages and structures.

They mainly concerns the following sections: 4) Materials and products; 5) Complementary materials; 6) Elements, typologies and structural systems; 7) Design rules and criteria; 8) Connections; 9) Specific rules for structural types and systems; 10) Design for earthquake resistance; Annexes) A – Timber grades, B – Coefficients for the design strength, D – Reference standards, E – Design of composite beams with flexible connections.

Hereafter the principal novelties are presented.

2 SECTION 4 – MATERIALS AND PRODUCTS

2.1 Material properties (Section 4.2)

This topic plays a crucial role for the durability of timber structures, then it deserves particular attention. Firstly, it has been remarked that timber elements must have a moisture content as much as possible equal to the environmental conditions of the construction in service. Moreover, it has been highlighted that the dimensional variations due to the moisture gradient cannot be neglected in the design phase. To this aim, for the first time a formulation to calculate the linear dimensional variations as a function of the moisture content of timber has been provided (section 4.2.2, eq. 4.3) and coefficients of swelling and shrinking of the wood, separately for solid and glue laminated timber, have been reported:

$$l_f = l_i\,(1 + k(u_f - u_i)) \qquad (4.3)$$

where l_i and l_f are the dimensions related to the initial and final moisture contents, respectively; k is the coefficient of swelling and shrinking of the wood in the considered anatomic direction; u_i and u_f are the initial and final moisture contents (%), respectively.

With regards to thermal variations (section 4.2.3), it has been pointed out that they are usually negligible for a single structural element, while in case of hybrid elements (i.e. concrete, timber, etc.) the interaction among them must be accurately checked.

Viscosity has been also introduced (section 4.2.4), considering that the creep could influence the structural behaviour of timber elements in service and ultimate conditions, affecting mechanical connections and coupled materials with different viscosity (i.e. timber-to-concrete composites beams).

2.2 Products (Section 4.3)

The range of structural products suitable for engineering applications has been expanded and more rationally reordered. In particular, as regards the solid wood elements two categories are considered: (i) solid wood and (ii) glued solid wood (with finger joints). There is no more the distinction between elements having rectangular and irregular transversal cross-section; besides the so called "uso Fiume" and "uso Trieste" beam types, having irregular transversal cross section (rounded corners) in the first case and both irregular cross section and variable cross section along the longitudinal axis in the second case are contemplated.

LVL beams, which are realized with thin glued wooden sheets (3 to 6 mm thick), have been added in the list of products, as well as CLT panels, largely used in the last years, and SWP panels (solid wood panel; Fig. 1). The relevant technological properties are also detailed.

With regards to the other panels types (OSB, particle boards, etc.) the references to relative standards, which rules constructional process, classification and testing, have been updated.

OSB CLT LVL

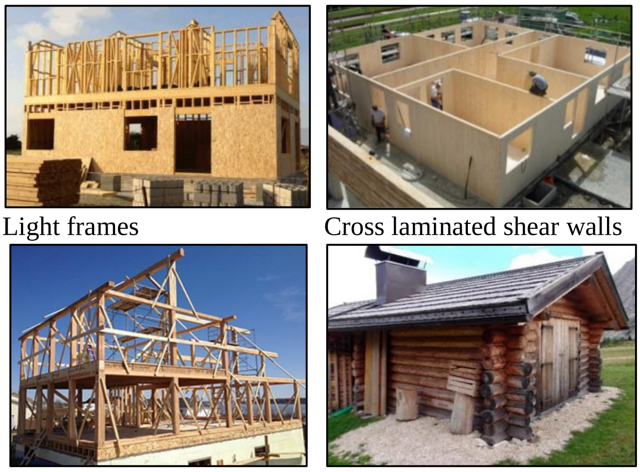
Figure 1. Example of timber based products.

3 SECTION 5 – COMPLEMENTARY MATERIALS

Additional details about adhesive and glueing process in field have been provided (section 5.1.2).

4 SECTION 6 – ELEMENTS, TYPOLOGIES AND STRUCTURAL SYSTEMS

The classification of the structural systems represents the novelty of the revised document. A hierarchical order among elements (beams, columns, beams with special shape, composites elements, panels), typologies (floor, walls, trusses, arches, frames) and structural systems for buildings (light frames, cross laminated shear walls, heavy frames, blockhaus, Fig. 2) is introduced and respected throughout the document. Each of them is accurately described, by technological and morphological points of view.



Light frames — Cross laminated shear walls

Heavy frames — Blockhaus

Figure 2. Structural systems for buildings.

Light-frame structures are buildings in which shear walls are made of timber frames to which a wood-based panel or other type of sheathing material are connected by means of screws, nails or staples and the shear walls are connected to the foundation or inter-storey floor by means of uplift and shear restrain mechanical connections.

Heavy timber frame structures are buildings in which the seismic actions are resisted by moment resisting frames with beams and columns connected through rigid or semi-rigid joints, or by timber frames with pinned joints coupled with concentric or eccentric bracing systems, or timber walls (Faggiano and Iovane, 2016).

Cross laminated timber (CLT or X-Lam) structures, are made of X-Lam shear walls connected together with mechanical connections. Shear walls may be monolithic, i.e. made with a single panel already including openings for doors and windows up to the maximum producible and transportable dimensions, or may be segmented i.e. made with X-Lam panels of limited dimensions connected together by means of vertical mechanical connections. According to the description, the seismic behaviour is mainly governed by the uplift and shear restrain connections placed at the base of shear walls. The construction system is generally a platform-type system, but it may be also a balloon-type system, in which case the walls behave like cantilever systems connected to the foundation and the floor to wall connection should be carefully designed.

In particular the Blockhaus (or log-house) structural type system is introduced for the first time, even though it belongs to traditional rural constructions (Fig. 3). It is commonly obtained by placing timber logs, horizontally, one over the other, so as to form a wall. The interaction between the logs is provided by corner joints and contact surfaces, so that the use of metal fastener is minimized. Floors are also made of timber.

Figure 3. Example of Blockhaus system components: typical shear wall, with corner joint and inter-storey floor.

Blockhaus is currently used in modern residential and commercial buildings, mostly for 1 or 2-storey structures. Design recommendations for walls under in-plane compressive loads, as well as for the seismic design are given (Bedon et al. 2014; 2019; Bedon & Fragiacomo, 2017).

5 SECTION 7 – DESIGN RULES AND CRITERIA

5.1 Service classes

The service classes (section 7.2) have been described with more details, adding also the definition of the corresponding “environment”, as it follows:

Service class 1: Indoor environment, heated during the winter.

Service class 2: Indoor environment, also not heated during the winter; outdoor environment, but not directly exposed to weather.

Service class 3: Environment where structures are directly exposed to weather or frequently exposed to moistening or even immersed.

Moreover the hygroscopic curves (Fig. 4) useful to determine the service class in case of non-standard thermo-hygrometric environmental conditions are introduced.

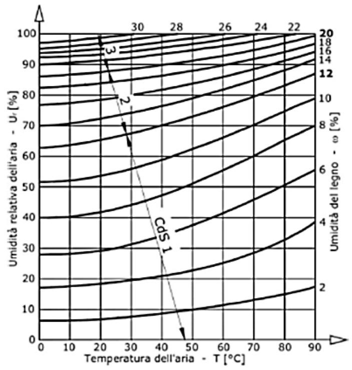


Figura 7-1 – Curve di equilibrio igroscopico per la definizione della classe di servizio.

Figure 4. Hygroscopic curves for the determination of the service class

5.2 *Serviceability limit state*

The method of calculation of deflection of members is more simply and clearly presented (section 7.5.1), as it follows:

$$w_{fin}=w_{inst}+w_{creep} \tag{7.2}$$

where w_{fin} is the initial instantaneous deflection, calculated with reference to the characteristic combination of loads, while w_{creep} is the creep deflection, which is calculated as it follows:

$$w_{creep}=w'_{i}\cdot k_{def} \tag{7.3}$$

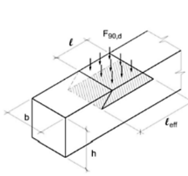
where w'_{i} is the initial instantaneous deflection calculated with reference to the quasi permanent combination of loads, while k_{def} is the reduction coefficient for deflections due to creep.

The section 7.5.4 related to vibrations has been extended and detailed.

5.3 *Ultimate limit state*

5.3.1 *Compression perpendicular to grains*

The values of the effective length l_{ef} that takes into consideration the effective loading area have been slightly modified and detailed (section 7.6.1.1.4, Fig. 5).



$$\sigma_{c,90,d}=\frac{F_{90,d}}{b\times l_{ef}}$$

$l\leq 400\text{mm}\rightarrow l_{ef}=l$

$l<400\text{mm}\rightarrow l_{ef}\geq l$

$$l_{ef}=\min\left(l+1/3\ h;\ 2l;\ 400\ \text{mm}\right) \tag{7.9}$$

$$l_{ef}=\min\left(l+1/6\ h;\ 1.5l;\ 400\ \text{mm}\right) \tag{7.10}$$

$$l_{ef}=\min\left(l+2\ l_{sc};\ 2l;\ 400\ \text{mm}\right)$$
$$l_{ef}=\min\left(l+l_{sc};\ 1.5l;\ 400\ \text{mm}\right) \tag{7.11}$$

Figure 5. Determination of the effective length of loading area.

Different cases are considered such as (7.9) at both sides of the loading area there is an unloaded area extended 1/6 h along the grain; (7.10) at one side of the loading area there is an unloaded area extended 1/6 h along the grain; (7.11) the length of the unloaded area (l_{sc}) is smaller than 1/6 h.

5.3.2 *Shear*

The coefficient k_{cf} of reduction of the cross section taking into account the cracking is introduced (section 7.6.1.1.9). It is equal to 0.67 for solid and glulam timber, to 1 for wood based products.

5.3.3 *Lateral torsional stability*

Coefficients β, for the determination of the effective length l_{eff} for the calculation of the critical moment M_{cr}, have been slightly modified (section 7.6.1.2.1, Table 7.4).

Table 1: Coefficient β for the calculation of l_{eff}

Beam type	Loading type	β
Simple supported	Constant moment	1.00
	Uniformly distributed load	0.88
	Concentrated force at the mid span	0.74
Cantilever	Uniformly distributed load	0.49
	Concentrated force at the free end	0.78

5.3.4 *Beams with web openings*

Values of the tensile force perpendicular to grains $F_{t,90,d}$ and the beam length $l_{t,90,d}$ subjected to tensile stresses perpendicular to grains have been defined (section 7.6.2.3).

5.3.5 *Composite beams and columns*

Reference is made to the γ method (details are given in annex 6) for taking into consideration the joint slipping for the determination of the states of stress and strain (section 7.6.3). Moreover design procedure are more clearly presented, also adding a specific example of calculation.

6 SECTION 8 - CONNECTIONS

6.1 *Carpentry joints*

Carpentry joints (section 8.2) deserve new attention, as they can again be easily and economically realized thanks to numerical control machines, while not many years ago they were abandoned in favour of metal fasteners, due to the high costs of skilled labor. Moreover several types of carpentry joints are present in ancient buildings, where their assessment is often required.

The section 8.2 has been significantly extended, describing the most common types of joints (Fig. 6), as those present in wood trusses, giving formulas to check the compressive and shear stresses and dimensional limits (Parisi and Cordiè, 2010; Branco and Descamps, 2015) .

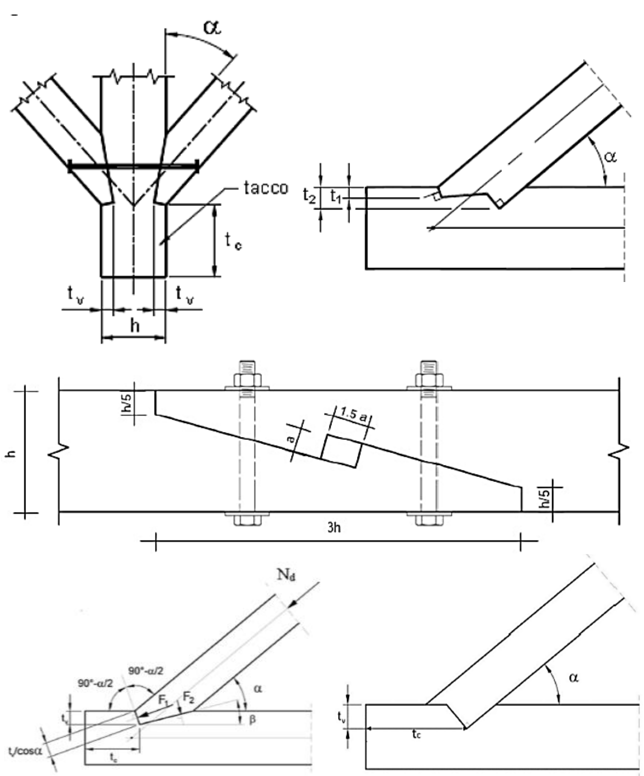


Figure 6. Carpentry joints.

6.2 *Connections with metal fasteners*

The related section 8.3 has been reorganized in order to be more clear and comprehensive. Cylindrical shank fasteners, as nails, dowels, bolts, screws are firstly described (Aicher et al., 2014), together with the principal mechanical characteristics, to address also the practitioners who face for the first time the design of timber structures.

The capacity of multiple fastener connections and multiple shear plane connections is described in its generality. Timber-to-timber and panel-to-timber connections and steel-to-timber connections resistances are based on Johansen's theory. The different failure modes are illustrated (Blass et al. 1995; Smith and Foliente, 2002).

Then the equations for the evaluation of the capacity of the different types of connection with metal fasteners are given according to the in force version of Eurocode 5. Main issues are first described in a general view and then declined for each different type. In particular formulas have been modified as dimensionless, wherever possible.

In case of bolted connection the equation for the evaluation of the yielding moment M_y is rewritten in such a way that the mechanical meaning is clearer with respect to the corresponding formula of EC5, given anyhow the same results:

$$M_{yk} = \zeta\, f_{uk}\, W_{pl,b} \tag{8.32}$$

This is valid for bolts diameter up to 30mm. $f_{u,k}$ is the characteristic value of the ultimate tensile strength; $\zeta = (do/d)^{0.4}$ is the reduction factor of the plastic moment that accounts for the ultimate behavior of the connector; d_0 is a reference conventional diameter equal to 4.35mm and d is the bolt diameter in mm; $W_{pl,b} = d^3/6$ is the plastic modulus of the bolt.

New types of joints as the glued-in rod joints are described and equations are given for the capacity evaluation in case of bars embedded in the fiber direction or inclined (Gattesco et al, 2017).

The stiffness evaluation for cylindrical shank connectors is updated and clearly reported in Table 8.14 for the different types of fasteners.

Table 2 - K_{ser} (N/mm) in timber to timber connections, for single connector and single shear plane, as a function of the diameter of the element (d, in mm) and of the average value of timber density (ρ_m, in kg/m^3)

Connector type	K_{ser} (N/mm)
Dowels, screws, nails with predrilling	$\rho_m^{1.5}\frac{d}{23}$
Nails without predrilling	$\rho_m^{1.5}\frac{d^{0.8}}{30}$
Staples	$\rho_m^{1.5}\frac{d^{0.8}}{80}$
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Particular attention is devoted to the details in all the illustrated cases.

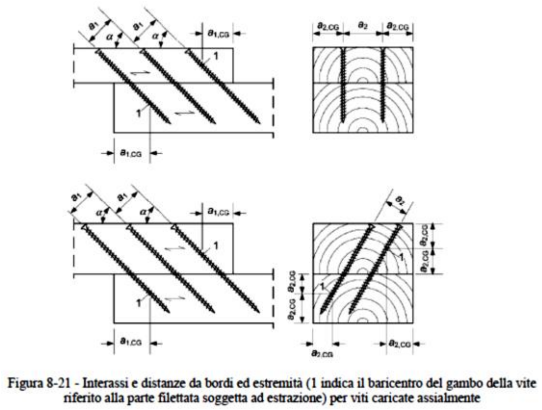


Figure 7: Details for axially loaded screws

An example of a steel to timber bolted connection in the Appendix F illustrates the application of the code equations.

7 SECTION 9 - SPECIFIC RULES FOR STRUCTURAL TYPES AND SYSTEMS

With reference to the definitions given in section 6, specific rules for the structural types have been integrated and those for the structural systems have been included for the first time.

8 SECTION 10 - DESIGN FOR EARTHQUAKE RESISTANCE

Surely, the seismic design of timber buildings is a key topic of the CNR document: in analogy with the other structural systems (i.e. reinforced concrete and steel buildings) the capacity design approach is considered also to design timber structures in seismic prone area (Faggiano and Iovane, 2016; Casagrande et al., 2019). Then, the plastic behavior of the connection elements, behaviour factors, ductility classes and hierarchy of strength to be used in linear static analyses are described in detail.

The section is partly based on the new provisions included in the revision of the chapter for the seismic design of timber buildings, still under discussion within the Standard Committee TC 250/SC8/WG3 (Follesa et al., 2018).

It has been articulated in the following subsections: 10.1 Actions; 10.2 Behaviour of structural systems; 10.3 Plastic behaviour, behaviour factors, ductility classes and capacity design; 10.4 Structural analysis: specific rules for structural typologies; 10.5 Life safety limit state checks; 10.6 Damage limit state checks.

Earthquake-resistant timber buildings shall be designed in accordance with one of the following concepts:

a) Low-dissipative structural behaviour;

b) High- or Moderate-dissipative structural behaviour.

In concept a) the design spectrum can be applied with a behaviour factor q not greater than 1.5.

In concept b) the value of the behaviour factor is given in Table 10.1 according to the structural type and assigned ductility class (High “A” or Medium “B”). Dissipative zones are generally assumed to be located in mechanical joints, whereas timber members behave elastically.

Structures may be classified in ductility classes A or B without any further specification if the following conditions for the mechanical connections in the dissipative zones are met: brittle failure modes like splitting, shear plug, tear out and tensile fracture of wood in the connection regions are avoided; for timber-to-timber dissipative connections, the failure mode is a ductile failure mode characterized by the formation of two plastic hinges in the metal fastener for DCA, one plastic hinge in the metal fastener for DCB. Some design criteria for structural details characterizing the ductility classes are also given.

Table 3 – Behaviour factors qo for buildings

STRUCTURAL TYPE	DCA	DCB
Light-frame structures	4.0	2.5
Heavy timber moment resisting frames	4.0	2.5
Heavy timber braced frames	-	2.0
X-Lam buildings	3.0	2.0
Blockhaus buildings	-	2.0

To ensure yielding of the dissipative zones, all non-dissipative members and connections in DC “A” or DC “B” structures should be designed according to hierarchy resistance criteria. Therefore the design strength of the brittle components should not be less than the design strength of the ductile parts multiplied by an overstrength factor. The latter should be equal to 1.6 for heavy moment-resisting timber frames and vertical cantilever walls and 1.3 for all other structural types in DCA, and respectively 1.4 and 1.1 in DCB.

Horizontal diaphragms should be designed against a design seismic load increased by a factor equal to 1.3 and connections to the seismic resistant vertical structures should be also designed with an overstrength factor equal to 1.3 in DCA and 1.1 in DCB.

9 ANNEXES

A-Timber grades

The timber grades are presented extensively. Additional hardwood grades have been included (Table A.2). Concerning softwoods, Italian firs have been grouped in a single category with two grades, while the larch pine has been also included (Table A.3). Concerning Glulam timber, grades GL20 and GL22 have been added, GL36 cancelled (Table A.5).

B-Coefficients for the design strength

Annex B is now related to coefficients for the determination of the design strength, such as γ_M and k_{mod}.

C-Coefficients for the calculation of deformation

Annex C is now related to the coefficients for the determination of deformation, such as k_{def}.

D-Reference standards

All the references to standards have been updated.

E - Design of composite beams with flexible connection

A new Annex is focused on the analytical calculation of composite beams (timber-timber or timber-concrete) with flexible shear connection (Fig. 7).

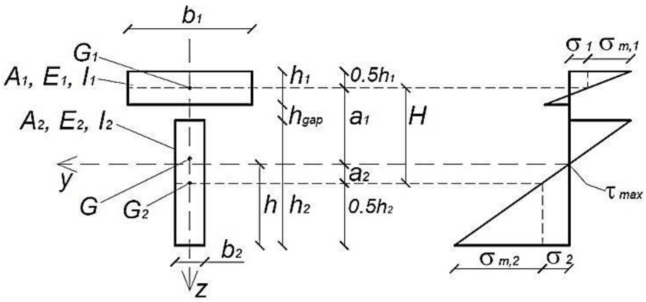


Figure 8. Reference cross-section for a composite beam with flexible connection and subjected to flexure, with corresponding distribution of normal stresses.

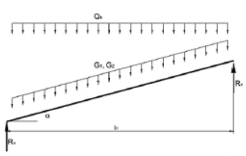
The proposal and content of the Annex is based on the well-known γ-method. The analytical approach, originally proposed in (Möhler, 1956), assumes that *s*-spaced flexible connectors are used to bond the beam components, besides the materials used have a linear elastic behaviour, with E_i as the longitudinal MOE for the *i*-th component.

The key aspect of the γ-method – widely used in general for composite beams– is represented by the use of simple analytical formulations to account for the actual bending stresses and deformations of each system component.

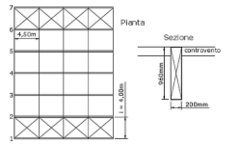
9.1 F-Examples of calculations

Examples of calculation have been included in Annex F (Fig. 8). The following case studies are developed: an inclined roofing beam; a braced roofing beam; column instability; steel-timber bolted connection; composite timber concrete floor.

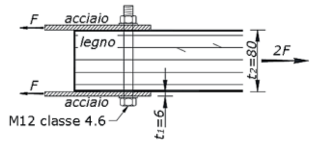
Inclined roofing beam



Braced roofing beam



Steel-timber bolted connection



Composite timber concrete floor

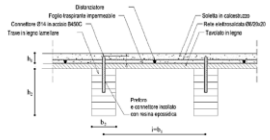


Figure 9. Some examples of calculation.

10 CONCLUSIVE REMARKS

Compared to most of the currently available standards for the design of timber structures, where no analytical models or verification approaches are provided for these systems, the CNR document receives the demand of designers and moves towards the definition of appropriate design regulations.

CNR DT206/R1-2018 reflects the most advanced knowledge on the behaviour and design of the new generation of timber structures, touching upon all the peculiar related issues.

The range of structural products is rationalized and expanded, including also CLT panels, which are surely the most used product for timber building constructions in the last years in Italy (sect. 4). As regards the wood-based materials and products, changes are made for the determination of the service classes: the hygroscopic curves in case of non-standard thermo-hygrometric environmental conditions are introduced. Moreover, the problems of thermal variation and creep phenomenon is faced providing more details for evaluating the dimensional variations of the material.

The document is organized establishing a hierarchical order among structural members, types and systems for timber buildings, which is followed throughout the document, providing technological and morphological descriptions (sect. 6), the structural configuration to resist gravity loads and seismic actions (sect. 9, 10) and the related design rules. It has to be noted that while timber-based elements and typologies were already described in the previous document (even if in a random order), the classification and characterization of the structural systems are introduced in an Italian Standards for the first time.

The strength and stability checks of the elements at Ultimate Limit States (sect. 7) are not substantially modified, except for the orthogonal-to-grain compression and shear checks and for the lateral torsional buckling check (i.e. review of the effective length); besides, the calculation of flexural deformations of the members at Service Limit States are slightly rewritten, although the basic concepts remain the same.

Surely, the seismic design of timber buildings is a key topic of the CNR document: in analogy with the other structural systems (i.e. reinforced concrete and steel buildings) the 'capacity design' approach is considered also to design timber structures in seismic prone area. Then, the plastic behavior of the (connection) elements, behaviour factors, ductility classes and hierarchy of strength to be used in linear static analyses are described in detail.

Some changes to the section of the connections systems (sect. 8), especially for traditional ones, are also applied. The range of traditional connection typologies is extended, also in the light of the most diffused types found in historical constructions. Conversely, few modifications are applied to the cases of steel-to-timber mechanical connections.

More annexes are included in the new version of the document. In particular, changes are applied to the annex which contains the strength profiles (appendix A) with the introduction of new strength profiles for both solid wood and glue laminated timber elements. As novelty, the calculus of composites beams performed with the so called γ-method is contemplated within a specific appendix (also according to Eurocode 5); similarly, a new appendix (F), which provides some practical examples relative to the most common structural systems (roof beams, timber-to-concrete composites floors, mechanical connection, etc.) is added too.

The activity of the committee is still in progress, with the aim of a continuous update and improvement of the technical document according to the advancement of knowledges.

ACKNOWLEGMENTS

The Italian national project DPC/ReLUIS 2019/2021, as well as the National Research Council (CNR) are acknowledged.

REFERENCES

Aicher, Simon, Reinhardt, H. -W., Garrecht, Harald (Eds.) 2014 . Materials and Joints in Timber Structures, Recent Developments of Technology, Rilem Bookseries, Volume 9, Springer, doi:10.1007/978-94-007-7811-5

Bedon, C., Fragiacomo, M., Amadio, C., Sadoch, C., 2014. Experimental study and numerical investigation of Blockhaus shear walls subjected to in-plane seismic loads. *Journal of Structural Engineering*, **141**(4), https://doi.org/10.1061/(ASCE)ST.1943-541X.0001065

Bedon, C., Fragiacomo, M., 2017. Derivation of buckling design curves via FE modelling for in-plane compressed timber log-walls in accordance with the Eurocode 5. *European Journal of Wood and Wood Products*, **75**(3), 449-465

Bedon, C., Rinaldin, G., Fragiacomo, M:, Noè, S., 2019. q-factor estimation for 3D log-house timber buildings via Finite Element analyses. *Soil Dynamics and Earthquake Engineering*, **116**, 215-229

Blass, H., Aune, P., Choo, B. S., Goerlacher, R., Griffiths, D. R., Hilson, B. O., Racher, P., and Steck, G. (1995). Timber Engineering Step 1 (Sec. C—Joints), Centrum Hout, The Netherlands.

Branco, J.M., Descamps,T. (2015) Analysis and strengthening of carpentry joints, Construction and Building Materials,Volume 97, Pages 34-47, doi:10.1016/j.conbuildmat.2015.05.089.

Casagrande, D., Doudak, G. & Polastri, A. (2019). A proposal for the capacity-design at wall- and building-level in light-frame and cross-laminated timber buildings. *Bull Earthquake Eng* 17: 3139. doi: 10.1007/s10518-019-00578-4

Faggiano B., Iovane G. (2016). First considerations on the design approach and criteria for seismic resistant moment resisting and bracings timber frames. In World Conference on Timber Engineering, WCTE2016, 22-25 August, Vienna, Austria, CD-ROM. Full paper ID1094.

Follesa, M.; Fragiacomo, M.; Casagrande, D.; Tomasi, R.; Piazza, M.; Vassallo, D.; Canetti D.; Rossi, S., 2018. The New Provisions for the Seismic Design of Timber Buildings in Europe. *Engineering Structures* **168**(2018) 736–747. doi:10.1016/j.engstruct.2018.04.090.

Federlegno Arredo (2018). Terzo rapporto case ed edifici in legno 2018.

Gattesco,N., Gubana,A., Buttazzi,M., Melotto,M. (2017) Experimental investigation on the behavior of glued-in rod joints in timber beams subjected to monotonic and cyclic loading, Engineering Structures, Volume 147,2, 372-384, doi:10.1016/j.engstruct.2017.03.078.

Möhler, K., 1956. Über das Tragverhalten von Biegerträgern und Druckstäben mit zusammengestezten Querschnitten und nachgiebigen Verbindungsmitteln. Habilitation, Technische Universität Karlsruhe, Germany.

Parisi,M.A., Cordié,C. (2010) Mechanical behavior of double-step timber joints, Construction and Building Materials,Volume 24, Issue 8, 1364-1371, doi:10.1016/j.conbuildmat.2010.01.001.

Smith,I. and Foliente G. (2002) Load and Resistance Factor Design of Timber Joints: International Practice and Future Direction, Journal of Structural Engineering,Vol. 128 (1) doi:10.1061/(ASCE)0733-9445(2002)128:1(48)