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COMBINE USE OF NDT/SDT METHODS FOR ASSESSMENT OF STRUCTURAL TIMBER MEMBERS

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COMBINED METHOD FOR THE IN SITU MECHANICAL IDENTIFICATION OF ANCIENT TIMBER BASED ON NDTS

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Abstract The research context. A wide research activity based on experimental tests and statistical analysis, is ongoing at the Department of Structures for Engineering and Architecture of the University of Naples Federico II, by the research team leaded by B. Faggiano, composed by M.R. Grippa, A. Marzo, L.Esposito. The research aims at providing a methodology for in situ mechanical identification of ancient timber members by non-destructive techniques [1, 2]. In particular the main goals are: database collection through laboratory NDT and DT investigations; mechanical characterization of old chestnut defect-free and structural elements through compression and bending tests; elaboration of experimental results for evaluating the influence of typical defect patterns on timber performances; identification of reliable NDT-DT correlations to be used in situ for the estimation of wood density, strength and stiffness properties; definition of standardized guidelines for practical applications. The starting point is the research carried out within the national project PRIN2006 “Consolidation of timber structures” (Prof. M. Piazza coordinator, B. Faggiano responsible of research unit) and the international project PROHITECH “Earthquake Protection of Historical Buildings by Reversible Mixed Technology” (2004-2008, prof. F.M. Mazzolani coordinator). The activity is actually developed in the framework of the Italian projects DPC-RELUIS 2010 – 2013 and 2014 (B. Faggiano responsible of research unit). The study is articulated in three main phases correlated each other, such as experimental investigations, data processing, structural identification by combined NDT-DT relationships.

Supplying of the test material

The experimental campaign is developed on timber elements made of old chestnut wood (Castanea sativa Mill.), provided from roofing trusses of masonry buildings in Naples, dated beginning of 19th century. Tests are performed on both structural

elements and defect free specimens with standard dimensions, according to UNI EN 480 (2004) and UNI ISO 3789 and 3132 Italian codes (1985), in order to evaluate the influence of defect patterns on both non-destructive quantities and mechanical properties measured through destructive tests [3, 4, 5]. Specimens have the following features (Fig. 1):

Fig. 1. Specimens tested in the experimental activity.

- Structural elements in actual dimensions (S_A): from trusses king posts, 14 elements (S_A-C) for compression tests parallel to grain, D 14.5-16 cm mean equivalent diameter, 6D length; from the trusses struts, 10 elements (S_A-B) for bending tests, D 15-16.5 cm mean diameter, 19D length;
- Squared elements in small dimensions (SS): from 11 S_A-C specimens, after destructive tests: 20 samples 5x5x30 cm for ND and D tests in compression parallel to grain (S_S-C); 16 elements 5x5x15 cm for ND tests (S_S-NDT); from 6 S_A-B specimens, after destructive tests: 24 elements (undamaged parts, 4 from each specimen) 4x4x76 cm for ND and D tests in bending (S_S-B);
- Defect-free specimens (DF): from S_A-C samples, 2x2x4 cm: 33 specimens for longitudinal tests (DF-C_L); 22+22 specimens for both radial (DF-C_R) and tangential (DF-C_T) tests; from S_A-B samples, 2x2x40 cm: 35 specimens for bending tests (DF-B).

Table 1 specifies for each group of specimens the ND and D tests performed.

Table 1. Non-Destructive (H: hygrometric; U: ultrasonic; S: sclerometric; R: resistographic) and Destructive (C: compression; B: bending) Tests.

Specimens		Non-destructive tests (NDT)				Destructive tests (DT)		
type	n.	H	U	S	R	C //	C ⊥	B
S_A-C	14	x	x	x	x	x		
S_A-B	10	x	x	x	x			x
S_S-C	20	x		x	x	x		
S_S-NDT	16	x		x	x			
S_S-B	24	x		x	x			x
DF-C_L	33	x				x		
DF-C_R	22	x					x	
DF-C_T	22	x					x	
DF-B	35	x						x

Visual inspection

Preliminary, the conservation state of the selected elements is examined by checking timber features and defects, signs of damage and deterioration. In particular, on the lateral faces of S_A-C specimens macroscopic longitudinal cracks due to shrinkage are detected; whereas, ring shakes, large isolated knots or knots groups are surveyed on the S_A-B specimens. Therefore, as a result of the visual structural grading, according to UNI 11119 (2004) standard, all specimens are assigned to the third class.

Non-destructive tests (NDT).

The following ND techniques are employed [3]:

- Hygrometric tests, for the evaluation of the moisture content of wood;
- Ultrasonic (*U*) tests, for the determination of the elastic properties of wood;
- Sclerometric (*S*) tests, for the assessment of the quality and surface hardness;
- Resistographic (*R*) tests, for the detection of density variations and internal defects of wood.

For each specimen, the average values of NDT measures, such as ultrasonic stress wave speed (*SWS*), sclerometric penetration depth (*PD*), resistographic mean amplitude (A_m), are calculated.

Since in situ surveys allow only perpendicular to grain measures on the accessible external surfaces of timber members, laboratory tests are performed in both longitudinal (L) and transversal (T) directions as respect to grain orientation for evaluating the relations between L and T ND variables.

Destructive tests (DT)

Compression (C) and bending (B) tests were carried out for determining the mechanical behaviour of timber elements in terms of stiffness, load bearing capacity and collapse mechanisms [4].

Statistical analysis of laboratory data

The experimental results are critically examined and compared, with aim to obtain statistical ND and D parameters, such as average values, standard deviations and coefficients of variation.

Determination of NDT-DT correlations

By means of a linear regression approach the following relations are examined [1, 7]:

- Correlations between NDT parameters, relating the L and T measures by U, S and R tests;
- Correlations between DT parameters, defining the mechanical behaviour in C and B;
- NDT-DT correlations, using both simple and multiple models for ND estimation of density, modulus of elasticity and strength of the material.

In order to identify the best combination of NDT parameters for the prediction of wood density, simple and multiple linear regression analyses have been carried out. The goodness of regression fit, such as the fitting of the linear model to a given body of data, is formally assessed by the coefficient of determination (R^2). Note that $0 \leq R^2 \leq 1$, high values indicate a strong linear relationship between the variables involved in the model.

As an example simple and multiple correlations are presented in Fig. 2.

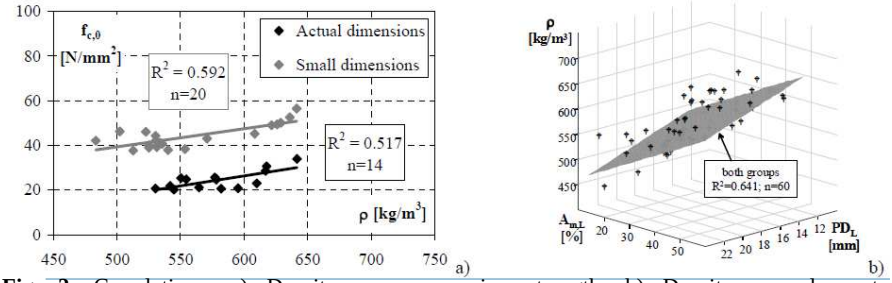

Fig. 2. Correlations: a) Density vs compression strength; b) Density vs sclerometric+resistographic parameters

Combined method for timber mechanical characterization

Based on the results achieved, the method consists in the determination of the density of timber through the combination of in situ sclerometric and resistographic

parameters in transverse direction. Once estimated the density, the strength and modulus of elasticity both in compression and in bending are evaluated through the correlation with density. Indication for executions are also provided.

Further development

The extension of the database would allow to reach more and more robust correlations for in situ mechanical characterization of existing timber members.

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