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TESTING CALIBRATION ISSUES IN RESISTANCE DRILLING APPLIED TO TIMBER ELEMENTS

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Keywords: Timber, resistance drilling, needle consumption, densiometric profile, NDT visual inspection, wood classification

Abstract.
Resistance drilling devices are commonly used for the onsite inspection of wood and timber structural components in existing buildings. Although they provide a measure related to the density variation along a section of an element, results are used mainly qualitatively, due to several parameters that affect the computed values.
In this paper, several new and old timber elements, taken from the dismantling of original roofs from a large existing historical building in northern Italy, are tested through a series of ND (non-destructive), SD (semi-destructive) and destructive testing procedures. Various wood species (spruce, fir, larch, oak, elm, pine) are taken into consideration.
Among the applied testing methods (visual inspection, resistance drill, ultrasonic, needle penetration, radar, lab tests bending/compression), not all reported here, a focus on the resistance drill tests results is addressed, to evaluate the influence of consumption of the needle tip on the amplitude output. This was done by correlating the drillings to a reference sample on each test position to obtain data with an enhanced quantitative content. From the visual old timber elements grading, SD tests execution and successive element strength characterization through laboratory tests, it finally emerged the need for proper calibration of assessment methodologies through the application of a combined approach, in order to achieve more reliable results.

1 INTRODUCTION

Diagnosis of current state of timber components in existing buildings is supported by investigation tools applied onsite as non-destructive (ND) and semi-destructive (SD) test

procedures [1][2]. Among them, resistance drilling devices [3] are commonly used to check the conservation condition of wood and detecting possible inner flaws, joints, etc. This device provides a densiometric profile along the investigated section, based on the drilling power consumption of a thin long needle driven into the wood at speed rates kept constant by electronic control [4]. Being a local test method, timber components in existing buildings often require multiple measures, depending on specific problems to investigate (e.g., beam ends threatened by moisture due to masonry contact, presence of decay, cracks).
The need of defining the state of conservation of existing timber elements, related to local material consistency, is often coupled with the request of element classification according to the reference standards for safety evaluations [5][6], which is related to the overall features of the timber element (mechanical damage, wood fibers angle, presence of knots).
The paper investigates some issues arising from the application of the resistance drilling method proposing test procedures aimed at minimizing the data inherent qualitative aspects, with the final goal to improve the existing timber elements classification methodology as proposed by the Italian reference technical standard [6].

2 EXPERIMENTAL ACTIVITY LAYOUT

The experimental program included a series of ND/SD tests on new and old structural timber elements, followed by destructive tests aimed at determining some mechanical properties of the elements. The non-invasive testing campaign took place at the Bozza srl timber company (located in Vigonza, Italy), while the mechanical tests were carried out in the laboratory for tests on building materials, in the Department of Civil, Architectural and Environmental Engineering of the University of Padua.
The timber beams investigated in the context of the work carried out were:
- 21 "old" beams of different species, recovered from the dismantling of the roof of the Moncucco farmhouse in Milan (now a student house of IULM University of Milan), having different dimensions and cross sections (Figure 1).
- 12 new beams (6 spruce and 6 larch beams), having a cross section of 160x160 mm and different lengths. The new beams are classified as C24 (spruce) and C22 (larch) according to the resistance classes of UNI EN 338 [5].

Figure 1: Timber beams ready to be tested at Bozza Legnami premises

2.1 Resistance drill distributed testing

Rather than obtain densiometric profiles of the timber elements in few or singular points, it was chosen a *distributed* test procedure, still considered feasible during onsite professional activity, to obtain an overall (averaged) drill resistance amplitude value. This attempt was done in order to take into consideration the presence of material inconsistency (cracks, decayed wood, etc.) with its balanced influence on the entire element. As acquisition pattern, a line of points with a regular spacing of 50 cm on orthogonal faces was chosen (Figure 2). Each beam was then investigated on two adjacent sides with about 4 to 10 measurement stations per side.

In all the tested points the equipment was not directly placed in contact with the timber: between the tip of the drill and the beam a C24 spruce timber sample of known height was placed. Such samples were parts of spruce boards classified C24, having a height of 27 mm and a moisture content of around 12% at the time of testing. To standardize the results and thus make them as homogeneous as possible, an attempt was made to cross perpendicularly the growth rings of the spruce sample elements with the tip of the drill.

The purpose of this procedure was to have a direct comparison between the density of the known wood with what was going to be tested, obtaining a first estimate of the relative density between the two materials; moreover, in this way it was possible to compare the various densiometric measurements with each other even if different settings of the instrument were used (i.e. velocity of penetration or rotation), as the outputs were normalized always referring to the initial portion of 27 mm of spruce (Figure 3).

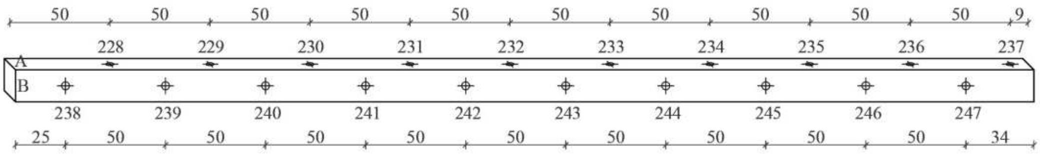


Figure 2: Test layout for beam L1 (larch): regular 50 cm spacing was selected on two orthogonal faces of beam

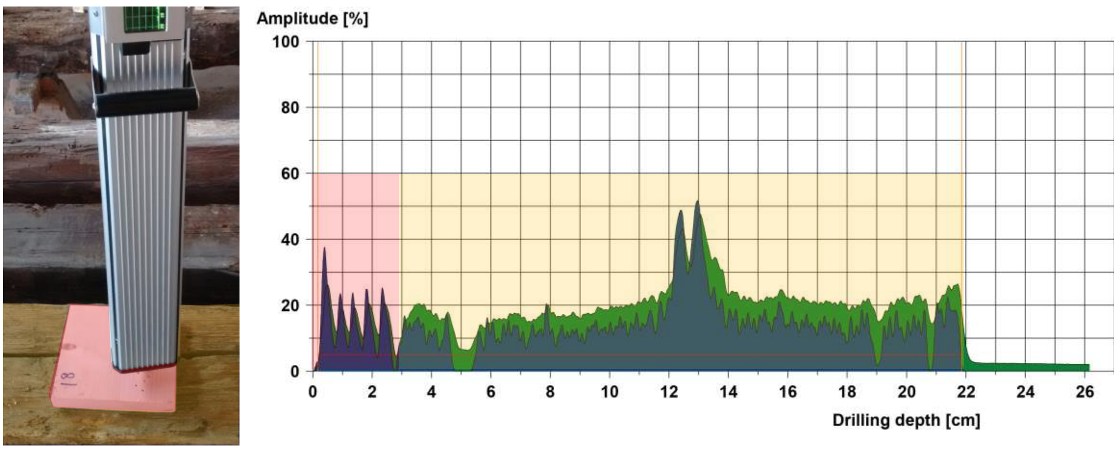


Figure 3: Element of known characteristics (spruce C24, height 27 mm) positioned between wood to be investigated and instrument, and corresponding densiometric profile (red: sample; yellow: tested element)

A quantitative parameter was chosen that could identify a summary value for each measurement made with the instrument:

$$RM = \frac{\int_0^l R(x)dx}{l}\% \tag{1}$$

where:
RM = averaged test amplitude value [%]
R(x) = instantaneous test amplitude value [%];
l = depth of needle penetration [mm].

The reference parameter was then RM_{norm}, intended as the ratio between RM calculated from a test position on the timber element and RM_{C24}, i.e. the RM value calculated only for the first 27 mm of known spruce; in both cases, the parameters were determined considering the "feed curve" of the used device [7]. The aggregate RM_{norm} values for all tests per each beam are shown in Figure 4. The C24 sample element applied on the timber surface of the investigated beams to compute normalized values of RM proposes indeed more informative data on the evaluation of the actual state of wood, for allowing immediate test results comparison among different cases and conditions. The use of the C24 spruce element allowed also to evaluate the trend of the RM value over time, observing how this increase with the number of the measurements. The use of a normalization element is therefore necessary as measurements performed on the same element at different times lead to different (increased) RM values (Figure 5).

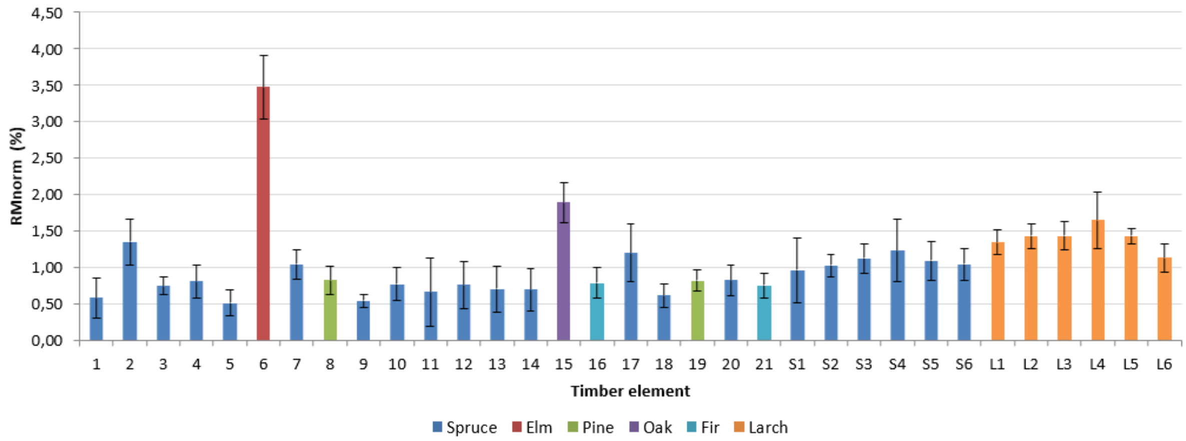


Figure 4: RM_{norm} values for all the tested timber elements, corresponding nr. 1-21 to old elements and acronyms S1-S6 / L1-L6 to spruce C24 and larch C22 new elements

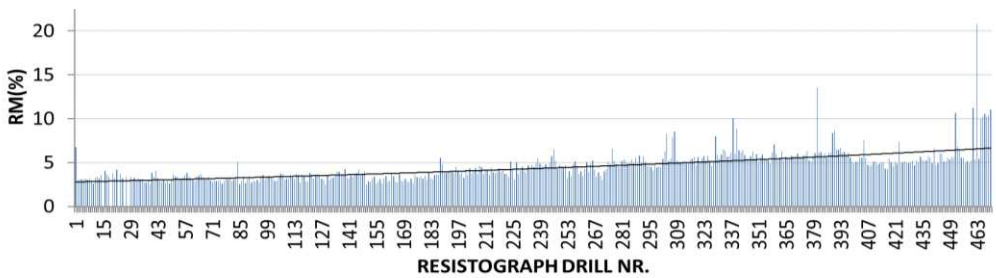
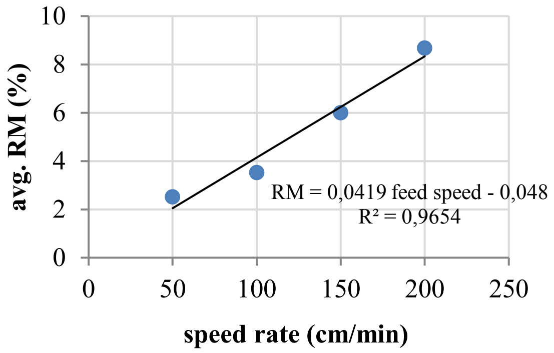


Figure 5: Influence of pin consumption on resistance drill amplitude chart on timber sample elements, which remarkably increases with the use of device

This phenomenon, likely due to the consumption of the tip of the resistance drill (tip sharpness progressively reduced), is not the only factor influencing the instrument outputs: it has been noticed that as the instrument settings vary (feed and rotation speed) the RM value is remarkably different. The influence of the drill settings in the amplitude response chart was quantified on the spruce sample element (27 mm thick at 12% MC, classified as C24 according to UNI EN 338 [5] by using various speed/rotation rates (keeping one parameter constant when varying the other and vice versa), thus obtaining relevant data for test output interpretation. For the same feed speed, RM will increase as the rotation speed decreases, while on the contrary it decreases with the penetration speed, with the same rotation speed (Figure 6).



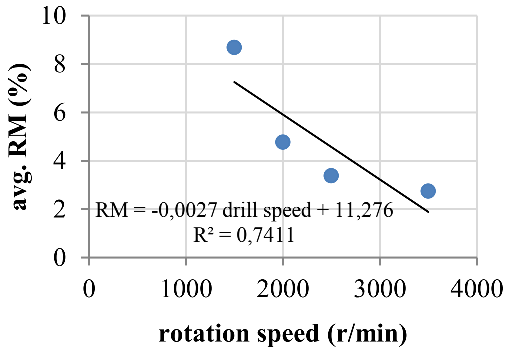


Figure 6: Drill resistance amplitude by varying feed speed and drill rotation speed (rpm)

3 MECHANICAL CHARACTERIZATION AND MD/D TESTS COMPARISON

Experimental laboratory tests were carried out with the aim of obtaining the mechanical parameters that can be correlated with the results of the non-destructive and semi-destructive tests carried out on the same timber elements. The tests carried out were bending and compression tests on real-scale elements (Figure 7).

Both types of test refer to the requirements indicated in UNI EN 408 [8], which specify the test methods and the dimensions of the samples. Tests involved 9 reused and 6 new timber elements.

Figure 7: Execution of mechanical tests at DICEA laboratory, according to EN 408 (compression/bending)

A comparison between the resistance drill averaged values RM and the mechanical characteristics emerged from the laboratory tests are given in Figure 8. As it can be seen, the correlation coefficient between $f_m/f_{c,0}$ vs. RM (charts above) is very low and almost no relationship can be established between the laboratory and onsite results. On the contrary, very interesting results emerge when plotting the mechanical results versus the parameter RM_{norm}, i.e., normalizing the average value on the sample element of known characteristics. This allowed to balance the overall densiometric profiles on a well characterized sample, depending from parameters (i.e., pin consumption) which are uncontrollable on site.

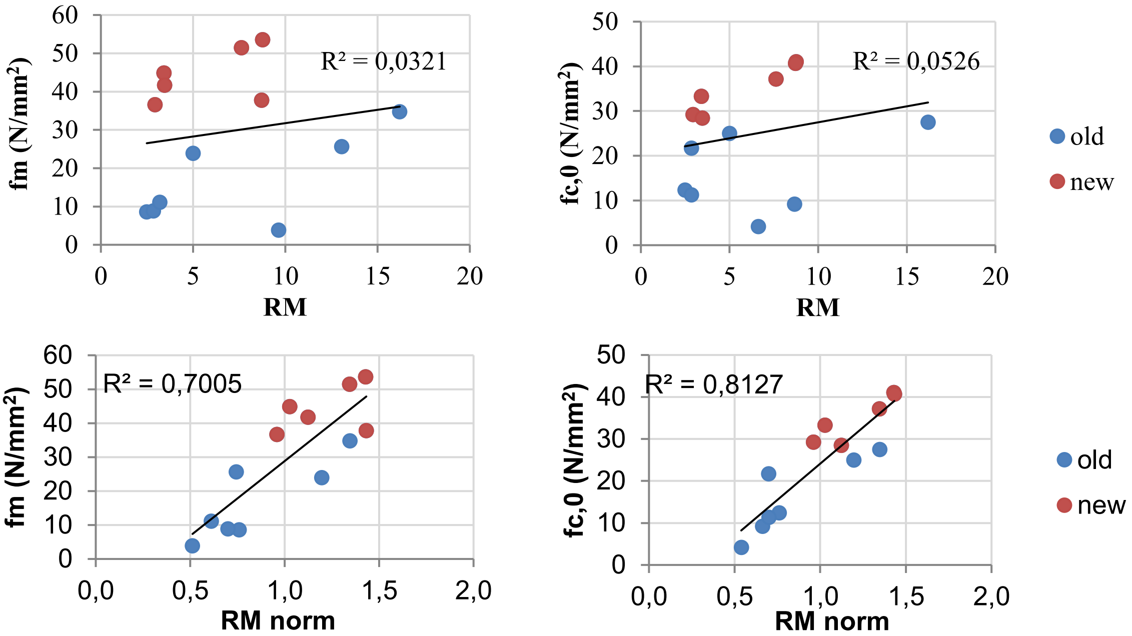


Figure 8: Correlation of mechanical characteristics of old and new timber elements in terms of compressive and flexural strength, versus the parameter RM (above) and RM_{norm} (below)

4 VISUAL INSPECTION AND ELEMENTS GRADING

The UNI 11119:2004 standard [6] (Cultural heritage, Wooden artefacts, Load-bearing structures of buildings - In situ inspection for the diagnosis of existing timber elements), indicates the classification rules and the methods for measuring the quantifiable characteristics on the structural existing timber elements. For assignment to a category, all characteristics and/or defects must fall within the specified limits (Table 1).

Starting from these indications it therefore reports, for wooden elements of different wood species and categories: (i) the maximum stresses, which can be adopted for the application of the allowable stress method; (ii) the average values of flexural modulus of elasticity, which can be used for the calculation of deformations of the structure in operating limit states.

All of the old timber elements of this experimental work were classified according to the UNI 11119 standard.

Table 1: Values for allowable stress extracted from table 1 and 3 of UNI 11119:2004 standard

Feature	Grade			Specie	Cat.	Compression // - ⊥ (N/mm^2)		Flexural (N/mm^2)
	I	II	III	fir	I	11	2	11,5
Edge chamfer	≤1/8	≤1/5	≤1/3		II	9	2	10
Shakes (star, ring,.)	absent	absent	limited		III	7	2	7,5
Single knots	≤1/5 ≤50 mm	≤1/3 ≤70 mm	≤1/2	spruce	I	10	2	11
					II	8	2	9
Grouped knots	≤2/5	≤2/3	≤3/4		III	6	2	7
Fiber angle radial	7%	12%	20%	larch	I	12	2	13
Fiber angle tangent	10%	20%	33%		II	10	2	11
splits	allowed if not passing				III	7,5	2	8,5

Visual grading is the basics of the new timber elements classification, and its counterpart for the existing elements on-site evaluation [6] represents a valid and viable assessment method. However, a single investigation method may not be totally adequate – especially in case of historical wood - for a correct assessment of the timber element under observation [1]. Results of the present experimental work showed remarkable discrepancies, even if on a reduced samples number, between the classification according to UNI 11119 and the mechanical characterization through laboratory tests, for some of the tested elements. Beams nr. 2, 5 and 9 were indeed classified in 1st (5, 9) or 2nd class (2), with reference values proposed by the standard – transposed to EN338 classes and related to the wood specie – respectively referable to C24 and C18. On the contrary, beams 5 and 9 (only tested in bending and compression, respectively), demonstrated a very weak response, with f_m and $f_{c,0}$ equal to 3.91 and 3,76 N/mm^2 respectively, which is far below any suggested value. Beam nr.2, a II class element, performed similarly to the new C24 spruce elements, with flexural and compression strength equal respectively to 34,76 N/mm^2 and 25,73 N/mm^2.

Comparing however the visual classification of the above mentioned elements with the distributed normalized Resitograph® amplitude RM_{norm} (Table 2), it can be seen that even if in class II, element nr. 2 had a remarkable RM_{norm} value (1,35), higher than the reference C24 sample element. At last, elements 5 and 9 had a very poor performance in terms of RM_{norm} values, equal respectively to 0,51 and 0,54.

Table 2: Mechanical tests results related with UNI 11119 elements classification

Sample	Specie	f_m (N/mm^2)	$f_{c,0}$ (N/mm^2)	RM_{norm} (%)	Cat. UNI 11119:2004
2B / 2C	spruce	34.76	25.73	1,35	II
3B	spruce	25.65	---	0,74	I
5B	spruce	3.91	---	0,51	I
9C	spruce	---	3.76	0,54	I
11C	spruce	---	6.88	0,66	I
12B / 12C	spruce	8.6	11.42	0,76	NC
13B / 13C	spruce	8.91	9.78	0,70	I
14C	spruce	---	19.05	0,70	II
17B / 17C	spruce	23.94	22.08	1,20	I

5 CONCLUSIONS

An experimental work concerning combination of methodologies for the on-site assessment of structural timber elements was carried out at the University of Padua by using available ND, SD and destructive investigation procedures. Results showed that:

- As part of the non-invasive methodologies for investigating wooden structural elements, it has been noted that the visual classification is not always sufficient to determine the mechanical characteristics in favor of safety, although it is the first step in the investigation procedure.
- Resistance drill tests propose quantitative results however limited to a single investigation point/investigated element, since it was noted that several parameters influence the test output, some of them basically uncontrollable (tip consumption).
- An attempt procedure for results generalization was employed, corresponding to a distributed resistance drill test application on the length of the element, employing per each test position a sample reference element of known mechanical characteristics.
- Satisfactory correlations in terms of determination coefficients were obtained plotting the normalized amplitude proposed parameter RM_{norm} with the mechanical characteristics of the elements derived from laboratory tests.
- The consideration of such parameter – substantially proposing distributed information on the inner sections (non-visible from outside) - seems promising to complement the strength class visual grading as prescribed by reference standards, possibly calibrating the given strength parameters today only related to the visual classification.

The authors will continue the investigations since it is noted a strong need for further relevant amount of data to be treated on a statistical basis.

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