J.F. Silva Gomes
Shaker A. Meguid
Editors

RECENT ADVANCES IN MECHANICS AND MATERIALS IN DESIGN

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About the Book:

During the last few decades the development of computer based techniques, as well as new experimental methods, nanotechnologies and nanomaterials, among many other material technological advances, added new dimension and perspectives to mechanical design and manufacturing of engineering systems, structures and components. Different tools are now available to optimize any engineering solution, and we must continue our efforts to develop and use superior materials, apply reliable analytical and numerical techniques and validate these with sound experimental methods.

This volume contains the extended Abstracts of papers accepted for presentation in the *M2D2015 - 6th International Conference on Mechanics and Materials in Design* held in Ponta Delgada/Portugal, 26-30 July 2015. The book is complemented by an accompanying CD-ROM containing the full length papers.

M2D2015 is part of a prestigious series of conferences that was initiated in 1996, in Toronto (Canada), coordinated by the International Scientific Committee on Mechanics and Materials in Design. The conference attracted over 320 participants with 423 accepted submissions from 42 different countries around the world. These papers were presented in July 26-30, 2015 in the magnificent city of Ponta Delgada-Azores, Portugal. The conference themes, which address novel and advanced topics in Mechanics and Materials in Design, focused on analytical and numerical tools at all scales, testing and diagnostics, surface and interface engineering, tribology, mechanical design and prototyping, modes of failure, composite and engineered materials, biomechanics, energy and thermo-fluid systems, impact and crashworthiness and case studies.

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EDITORS' PREFACE

M2D2015 is the sixth international gathering of a prestigious series of conferences coordinated by the International Scientific Committee of Mechanics and Materials in Design. This series of conferences are wholy devoted to advances in mechanics, materials, structural integrity and design. M2D2015 is sponsored by the University of Porto, the University of Toronto and the University of Azores. The conference attracted over 320 participants with 423 accepted submissions from 42 countries out of 620 submissions. These papers were presented in July 26-30, 2015 in the magnificent city of Ponta Delgada, Azores. The conference themes which address novel and advanced topics in Mechanics and Materials in Design focused on analytical and numerical tools at all scales, testing and diagnostics, surface and interface engineering, tribology, mechanical design and prototyping, modes of failure, composite and engineered materials, biomechanics, energy and thermo-fluid systems, impact and crashworthiness and case studies.

We believe that the meeting offered our delegates a forum for the dissemination of their recent work in mechanics and materials and their applications in engineering design, fostered research that integrates mechanics and materials in the design process, and promoted exchange of ideas and international co-operation among scientists and engineers in this important field of engineering.

We are particularly indebted to the authors and special guests for their presentations. Each of the more than 420 contributions offered opportunities for thorough discussions with the authors. Particularly, we acknowledge the excellent contributions of the participants, their innovative ideas and research directions, the novel modeling and simulation techniques, and the invaluable critical comments. We are also indebted to the outstanding keynote speakers who highlighted the conference themes with their contributions and covered the main topics of the conference. We also take this opportunity to thank the members of the International Scientific Committee and the reviewers for their time, effort and helpful suggestions.

We offer our sincere gratitude to the symposia organisers for their efforts and valuable contributions to the success of the event, and the local organising committee for attending to the conference demands and delegates needs.

All in all, M2D2015 was a great success and the credit must go to all the participants for their significant contributions and lively discussions, the keynote speakers for bridging the gap between the different disciplines and the organizing committee for an absolutely superb organization of the meeting in this magnificent city. To all of you, we offer our gratitude.

Given the rapidity with which science is advancing in all areas of mechanics and materials, the next conference in this series (Integrity, Reliability and Failure - IRF 2016) will take place in Porto, Portugal in July 2016. Undoubtedly, we expect IRF2016 to be as stimulating and interesting as M2D2015, as evidenced by the excellent contributions offered in this current event. We look forward to seeing all of you in Porto in 2016.

Shaker A. Meguid and J.F. Silva Gomes
P. Delgada / Azores, July 2015

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RECENT ADVANCES IN MECHANICS AND MATERIALS IN DESIGN

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PAPER REF: 5592

IMPLEMENTATION OF NON-METALLIC MEMBRANES INTO STEEL SUPPORTING STRUCTURES

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ABSTRACT

The paper deals with analysis of textile/foil membranes supported by peripheral non-rigid steel structures. Approaches to global analysis of light membrane structures which are presently required for both temporary and permanent structures are discussed. The investigation relates to geometrically non-linear analysis (GNA) of structures composed of prestressed membranes located between steel arch beams. Extensive parametric study concerning possibility of separate analyses of the membranes and supporting steel structures is presented, giving limiting parameters for such approach. Influence of construction procedures (introduction of prestressing) is also analysed.

Keywords: prestressing, structural analysis, steelwork, textile membranes.

INTRODUCTION

Textile membranes are becoming routine components to cover not only common shelters but also sophisticated outward load bearing structures (http://www.basestructures.com/). Design of membrane structures follows the general concept (Lewis, 2003): i) Pre-design of a form ensuring tension within all membrane area during assembly and loading, requiring sufficient prestressing: basic shapes are hypar, cone, barrel (Seidel, 2009). ii) Deciding on boundary conditions and elements (point/continuous, rigid/elastic, cables/frames/anchor points). iii) Form-finding process: physical model or numerical modeling (Linkwitz, 1999, Gründig, 2000). iv) Structural analysis of the membrane with supporting structure under prestressing, dead and live loading: snow, wind, facility (Foster, 2004, Wakefield, 1999). Prestressing procedure often determines the design and final geometry.

The paper deals with barrels and hypars (Fig. 1). Interaction with supporting steel non-rigid structure is analyzed to reveal necessity of full joint or potential simplified separate analyses (i.e. membrane on fictitious stiff supports and steel structure loaded by the relevant response).

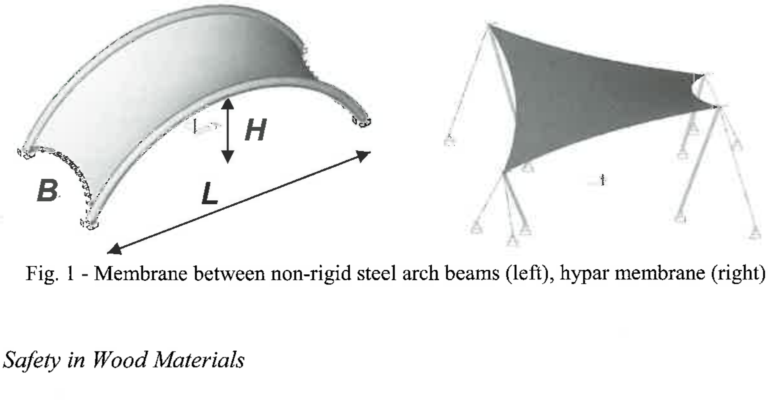

Fig. 1 - Membrane between non-rigid steel arch beams (left), hypar membrane (right)

RESULTS AND CONCLUSIONS

Parametric FEM nonlinear study of 27 membranes with various geometry *LxBxH* supported by adequate tube steel arches acc. to Fig. 1 was performed with a fictitious membrane (modulus of elasticity $E = 1000$ MPa, Poisson's ratio $\nu = 0.25$, thickness $t = 1$ mm), loaded by a directionless prestressing due to deformation of $\varepsilon \approx 0.004$ and transverse uniform loading 1 kN/m^2. From the results is obvious, that for arch span up to 9 m the interaction of arches with membrane may be neglected (analysis of the membranes with rigid supports and arches with resulting reactions gives reasonable results). Separated analysis for span above 10 m however, markedly underestimates both vertical membrane and horizontal arch deflections, which negatively influence cutting and prestressing process of membranes. Faulty results give separate analyses for majority of spans above 16 m, where the necessary prestressing for "membrane with arches" in comparison with "membrane alone - on rigid supports" should be much higher and in spite of such prestressing an enormous increase of membrane deflection must be expected.

The results may be related also to the arch slenderness (arch length to appropriate tube radius of gyration). For slenderness values under 100 the ratios for prestressing ensuring the same total transverse force (resulting from analyses of the membrane with arches to membrane with rigid supports) are in range 100÷112 % and ratios for the membrane vertical deflection between 101÷137 %. Slenderness' above 100 give the ratios in range 99÷134 % for prestressing and 129÷271% for deflections.

Construction procedure, i.e. activation of the prestressing was analyzed for hyperbolic paraboloid in acc. with Fig. 1. The prestressing may be achieved either by stretching out of the anchoring or by peripheral cables. While in the first case the pylons are tilted outward, in the second case inward. Way of the prestressing therefore influences the final membrane structure geometry, position and placing of rectification elements, cutting and local corner stresses of the membrane.

ACKNOWLEDGMENTS

Support of the Czech Grant Agency GACR No. 105/13/25781S is gratefully acknowledged.

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PAPER REF: 5599

FIRE RESISTANCE OF CELLULAR WOODEN SLABS WITH RECTANGULAR AND CIRCULAR PERFORATIONS

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ABSTRACT

This work presents a numerical approach in order to predict the behaviour and the performance of typical cellular wooden slabs with rectangular and circular perforations when submitted to fire conditions. For this purpose a 3D numerical model was validated with different experimental tests at real scale obtained in laboratory in four cellular wooden slabs. This study was conducted in accordance with European standard EN 1365-2 and using a fire resistance furnace which complies the requirements of EN 1363-1. The thermal performance of the slab and the charring rate of the exposed surface will be compared for each type of perforations.

Keywords: Cellular wooden slab, perforation, fire.

INTRODUCTION

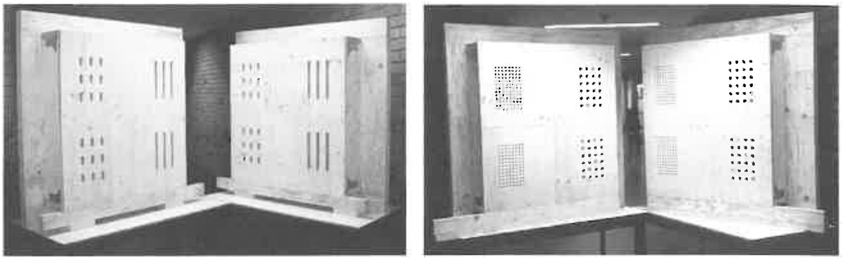
Wood when exposed to fire produces a surrounding charring depth layer, with no mechanical resistance, and causes a reduction in the cross-section element. In perforated cellular wooden slabs, the size of the perforations could influence the fire effect over the slab thickness. In this work, the main objectives are: present a numerical model validated with experimental tests to predict the evolution of the charring layer during a fire scenario using a finite element method with appropriate material properties and boundary conditions; determine the charring layer of different constructive solutions using wooden slabs with rectangular and circular perforations; determine the fire resistance in such way that contributes for a safe design in typical perforated wooden slab. The subject of this work is a study in progress according others investigations realized by the authors of this work (Fonseca et al. 2013).

WORK IN PROGRESS

In this work, four wooden slabs were considered for analysis. The geometric model of each slab considers three different cellular zones (two cells with different perforations and one cell with no perforation). Slab 1 and 2 present two types of rectangular perforations (250x20) mm and (40x20) mm, in the exposed surface. Slab 3 and slab 4 present circular perforations with a diameter equal to 10 mm and 20 mm, as represented in figures 1 and 2.

The slabs were tested on fire resistance furnace. In the experimental tests, thermocouples were installed to measure the temperature in different locations (unexposed surface of the floor plate, beams, steel connectors and cellular zones), see Fig. 3 respectively. For numerical simulation, a finite element method was used for nonlinear thermal transient analysis, using Ansys.

Fig. 1 - Wooden slab with cellular zones.



Slab 1 and slab 2.

Slab 3 and slab 4.

Fig. 2 - Cellular wooden slabs with rectangular and circular perforations.

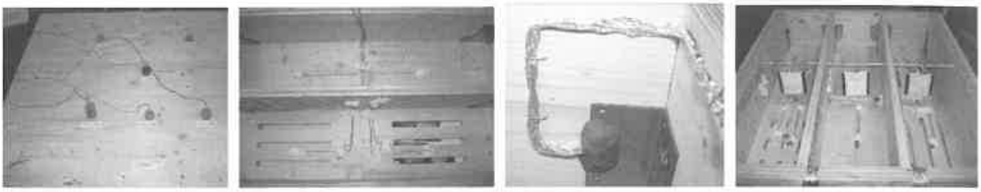


Fig. 3 - Thermocouples installation.

This study shows the evolution of the temperature and the char-layer throughout a wooden slab. The thermal behaviour of the each component was characterized and the evolution of the temperature inside the cellular zones. Also, the shape and the size of perforations could be assessed and compared with the unperforated cellular zone. The size of the perforation is responsible for different charring rates. The charring rate of the cell with no perforation is in accordance to the expected values of EN1995-1-2. The damage effect of fire is higher in the slab with larger perforations, as expected.

ACKNOWLEDGMENTS

The authors gratefully acknowledge to Jular company, who provided technical support for the wood slabs construction.

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PAPER REF: 5627

FIRE BEHAVIOUR OF TABIQUE WALL - EXPERIMENTAL AND NUMERICAL STUDY

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ABSTRACT

This paper present a study on the behaviour of *tabique* walls, concerning its fire resistance. This work is based on the experimental analysis of real scale *tabique* panels. Such panels were made in pine wood with an earth-based mortar finishing. In order to assess the earth-based mortar thickness effect on the fire resistance of the wall, three specimens were tested with different mortar thicknesses of 15 mm, 10 mm and 5 mm. The experimental models were tested in a fire-resistance furnace according to the ISO 834 standard fire curve. A numerical model was developed in order to assess the *tabique* wall behaviour under fire conditions and was validated with experimental results.

Keywords: Fire, *tabique*, traditional building techniques.

INTRODUCTION

The *tabique* is one of the main Portuguese traditional building techniques, which is based on raw materials as earth and wood. In general, a *tabique* wall is composed by a simple timber structure covered with an earth-based material. Nowadays, the existing *tabique* constructions show a generalized and advanced stage of deterioration (Cunha, 2014). This concern, along with the fact that there is still a lack of investigation in this field, motivated this work which main goal is to study experimentally and numerically the behaviour of the *tabique* wall under fire conditions using different earth-based mortar thicknesses.

The manufactures of *tabique* walls relies on a lightweight timber structure assembled with pine planks placed vertically on which horizontal battens are nailed on both sides (Araújo, 2014). In order to evaluate the earth-based mortar thickness effect, three panels with different mortar layer thicknesses of 15 mm, 10 mm and 5 mm were tested.

The thermal behaviour of *tabique* panels exposed to the fire action was evaluated using several thermocouples meant for measuring both internal and external temperatures of the wall. The entire procedure is based on (EN 1364-1, 1999). The main goal of this study is to assess the behaviour of the earth-based mortar layer that protects the timber structure which constitutes the *tabique* wall. Hence, thermocouples were placed at different depths in order to obtain temperature records inside the mortar (TA) and in wood (TM). The unexposed surface was also analysed with disk thermocouples (TD).

The specimens were tested in a fire-resistance furnace (Fig. 1) according to the ISO 834 standard fire curve. During the tests, the integrity of the panels was evaluated throughout the cotton pads test and gap gauges, as well as monitoring the test specimen regarding evidence of sustained flaming. However, there was a significant amount of smoke release from burning wood at final stage of the test, Fig. 2. The insulation was also evaluated during tests measuring the unexposed surface temperature.

Fig. 1 - Experimental *tabique* wall

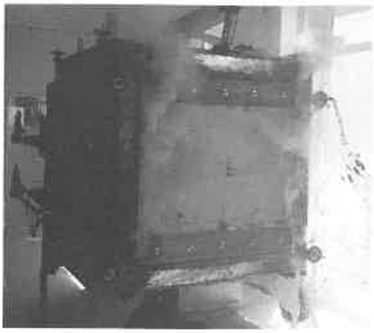

Fig. 2 - Smoke release

RESULTS AND CONCLUSIONS

The graphs in Fig. 3 and Fig. 4 show the obtained results from experimental fire exposure (T_e) and the numerical responses (T_n), in *tabique* panel with a 15 mm thick mortar layer, both for TM and TA thermocouples, respectively.

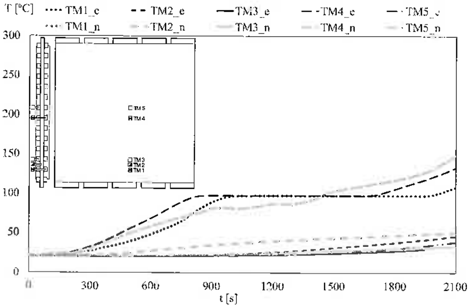

Fig. 3 - Time-temperature history on wood structure

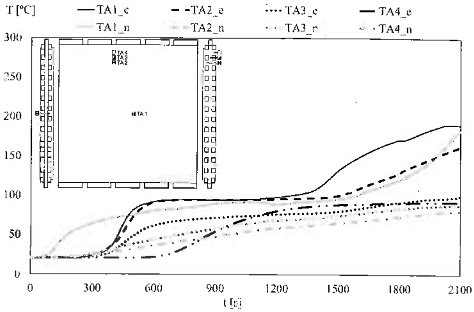

Fig. 4 - Time-temperature history on earth-based material

Experimental results allow the authors to point out that both performance criteria (insulation and integrity) defined according to the European standard for fire resistance tests (EN 1362-1, 1999) were fulfilled for the whole test duration of the three *tabique* panels. The numerical curves show good agreement with experimental results.

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PAPER REF: 5628

TENSILE STRENGTH OF PINE AND ASH WOODS - EXPERIMENTAL AND NUMERICAL STUDY

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ABSTRACT

Timber structures are a competitive solution when compared to steel and concrete structures, showing features and advantages that overcome their competitors: weight/strength ratio, rapid assembly, fire resistance and excellent performance in earthquake scenario, natural aesthetic attractiveness, and ecological rationality which leads to sustainable construction. The main goal of this experimental and numerical study was to evaluate, using tensile tests, the mechanical characteristics of two different wood species: Pine and Ash. For tensile test a total of twelve samples for each wood species were prepared, six of them were cut in the wood transverse to the grain, with dimensions equal to 190×50×9 mm, and the others six were cut in the wood parallel to the grain with the dimensions equal to 210×40×9 mm. A numerical simulation was also conducted in order to assess the stress-strain behaviour of Pine and Ash woods.

Keywords: wood, tensile strength.

INTRODUCTION

The mechanical properties define the behaviour of the timber when subjected to mechanical stresses, resulting directly from the timber anisotropic and heterogeneity properties. The tensile strength of wood being constant above the fibre saturation point, it increases with decreasing moisture content below the fibre saturation. This can be related to where the water is absorbed in the microstructure. Their study is of great interest for allowing the rational use of different wood species for structural and building purposes. The EN 408 standard defines the test procedure in order to obtain the mechanical properties of wood.

The tensile strength of wood parallel to the grain depends upon the strength of the fibres and is affected by the nature and dimensions of the wood elements, and also by their arrangement. The highest value is obtained in straight-grained specimens with thick-walled fibres.

Cross grain of any kind of material reduces the tensile strength of wood, since the tensile strength at right angles to the grain is only a small fraction of that parallel to the grain (Record, 2004). The wood properties are conditioned as well by the anatomical characteristics such as knots, cross grain and checks. Different values were obtained depending on four issues: compressive or tensile test, as well as the cut direction (parallel or transverse to the grain).

Comparatively, wood exhibits its maximum strength in tension parallel to the grain. Two different representative samples have been made of each wood specimen. Fig. 1 and Fig. 2 show the dimensions for specimens cut in wood transversally and parallel to the grain, respectively.

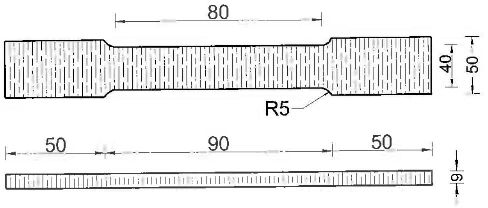

Fig. 1 - Specimen cut transverse to the grain

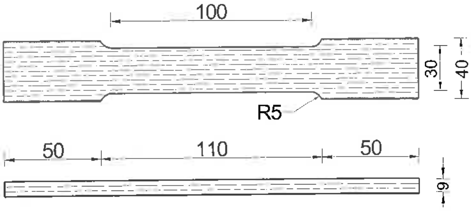

Fig. 2 - Specimen cut parallel to the grain

The experimental results were used to calibrate the numerical simulations conducted in ANSYS software with solid finite elements.

RESULTS AND CONCLUSIONS

The experimental and numerical results, from the tensile tests regarding Ash wood in the directions transverse and parallel to the grain, are shown in Fig. 3 and Fig. 4, respectively.

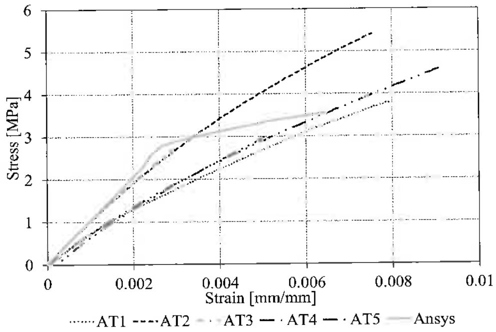

Fig. 3 - Stress-strain behaviour in Ash cut perpendicular to the grain

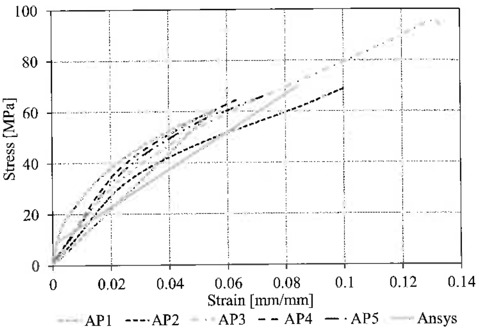

Fig. 4 - Stress-strain behaviour in Ash cut parallel to the grain

From results one can observe a highest strength in the parallel direction when compared with the one perpendicular to the grain. The specimens reached different tensile stress values corresponding to different strains. Regarding specimens cut in the longitudinal direction, an average value of 70 MPa was obtained, while for specimens cut in the transverse direction the tensile strength was less than 6 MPa. In both cases the wood presented a brittle behaviour. The numerical curves are in accordance with the experimental results.

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PAPER REF: 5686

CONSIDERATE SDT METHODS FOR SAFETY ASSESSMENT OF HISTORIC TIMBER

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ABSTRACT

The paper discusses approaches to safety assessment of historic timber structures using testing of very small specimens extracted from a historic structure or by direct in-situ testing. The presented methods take into account conditions given by the EN 16085. They further consider environmental influences and correlations of characteristics achieved by various SDTs.

Keywords: historic timber, in-situ compression testing, core compression test, moisture effect.

INTRODUCTION

Existing structures including the historic ones are typically tested for design or redesign and safety assessment purposes. The methods under discussion were selected for their possible application to historic timber structures, namely the listed and protected ones. In such a case, the sampling or in-situ test repetition is controlled not only by statistic imperatives but also by a necessity to accommodate relevant standards concerning interventions into historic tissue. Technical standardization committee CEN/TC 346 has prepared at least two standards which are applicable. The EN 16096 standard (August 2012) on "Conservation of cultural property - Condition survey and report of built cultural heritage" requires that assessment of condition of historic structures should be based on visual inspection combined with appropriate simple measurements. The following EN 16085 (August 2012) "Conservation of Cultural property - Methodology for sampling from materials of cultural property - General rules" defines basic approaches to extraction of material from historic structures, buildings or other objects. No specific rules or numbers of samples are suggested and all interventions must be individually designed by the assessor in the sampling plan taking into account the condition of the structure and objectives of sampling. Minimum intervention is a general rule and correlation with other NDT methods is recommended. The SDT, i.e. direct techniques should be preferably used for calibration or to prove estimates achievable by indirect NDT methods. Therefore, only core testing and mini-jack compression test methods are included.

SAFETY ASSESSMENT APPROACH

Both of the selected methods need a relatively small hole (about 10-12 mm) to be drilled into a historic structure. Contemporary core drilling technique has been developed in cooperation with prof. Bo Kasal and it is described in detail e.g. in Kasal et al. (2003). The method consists in parallel-to-grain compression of a small radial wood core of diameter of about 4.8 mm. The mini-jack compression test method has been recently introduced by the authors and it requires a special loading device that is able to compress wood directly in a small hole

(Drdácký & Kloiber, 2013). Both of these non-standard methods use testing of clear wood as all standard methods do. Therefore, the estimates obtained on clear wood by non-standard destructive tests can be used for transition to structural timber using the same approach and methodology as in the case of standard timber testing.

A question may arise concerning moisture content and its well known influence on wood characteristics. The material characteristics determined in situ, i.e. intrinsically containing all present imperfections and environment conditions provide an engineer with the data closest to reality and they need not be adjusted. In the case of destructive testing of samples in laboratory, it is generally possible to test "fresh" specimens retaining their in situ conditions. Nevertheless, the paper also presents data concerning the moisture influence on the measured values.

Transition of the core compression test data measured in laboratory can be advantageously supported by a strong correlation with the number of annual rings, which is discussed in the paper in detail and illustrated here in Fig. 1.

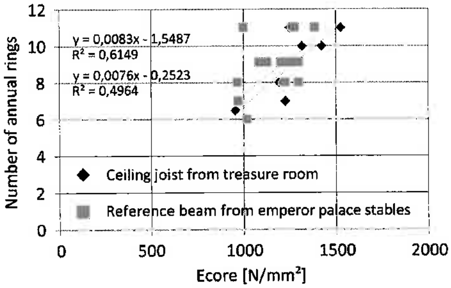

Fig. 1 - Correlation of number of annual rings with the Young modulus measured at core tests.

Naturally, testing of material characteristics is only one step in the whole process, and, because the testing approach can be considered a replacement of purely computation based standard approach, a natural subsequent step is checking of behavior, e.g. deformations, of the studied structure calculated using a theoretical model (with the measured material characteristics) by means of a proof load test of the whole structure.

ACKNOWLEDGMENTS

Support from the Czech Grant Agency Project P105/12/G059 and the NAKI Programme project DF11P01OVV001 funded by the Ministry of Culture is kindly ackowledged.

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PAPER REF: 5717

DETERMINATION OF CHARACTERISTIC VALUES IN NBR 7190/ 1997 FOR DESIGN AND FIRE SAFETY IN WOOD MATERIALS: HITS AND MISSES

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ABSTRACT

Annex B of the Brazilian standard for timber frame projects (NBR 7190:1997) have normative status and determines that the characteristic values of wood properties must be estimated by an expression that produces conservative estimates. In most situations, this strategy is suitable for design and fire safety in wooden materials due to the high variability of these materials. Unfortunately, the use of this criterion penalizes materials where great efforts were made to achieve a high level of quality control.

Keywords: Fire safety, wood materials.

INTRODUCTION

Standardization is an activity that determines repetitive and common use requirements, in order to obtain effectiveness and efficiency in actual or potential contexts. The protection of human life and health is one of its main objectives although its greatest use is to achieve a reduction of cost of production and the final product with maintenance or improvement of the quality.

The Brazilian Association of Technical Standards (ABNT) is the agency responsible for technical standardization in Brazil since its foundation in 1940 and is the official representative in Brazil of the following international organizations: ISO (International Organization for Standardization), IEC (International Electrotechnical Commission); and regional standardization bodies COPANT (Pan American Standards Commission) and the AMN (Mercosur Association for Standardization).

"According to the standard" is a phrase that appears 29, 72 and 66 times in the last three meetings in Brazilian Wood and Wooden Structures (2008, 2010, 2012) and is significant of a practice that, although experimentally and statistically inadequate, is recurrent in scientific works with wooden materials (Matos, 2013).

Values characteristic (X_{wk}) and average values taken from an experiment that followed the determinations of NBR 7190: 1997 on the performance of compression parallel to the fibers and the bending of the species *Erisma uncinatum (Vochysiaceae)* exposed to low risk fire conditions were simulated through simulation of pseudo random variables using Monte Carlo methods (Oliveira, 2012). The study simulated six variability conditions (coefficients of variation = 0.05, 0.10, 0.15, 0.20, 0.25, 0.30). Ten samples with normal distribution were generated 20000 times resulting from combinations of average values and levels of variability.

RESULTS AND CONCLUSIONS

The results from the simulations are shown in Fig. 1. An approximately quadratic relationship is shown by the characteristic values X_{wk} that are within the average confidence interval with maximum point for coefficient of variation equal to 0.20. The characteristic values X_{wk} that are outside the average confidence interval have an inverse pattern (Fig. 1A). The frequency of the largest characteristic values X_{wk} than the upper limit of the confidence interval is almost nil from variation coefficient values equal to 0.10. The estimate of the characteristic values X_{wk} is a conservative estimate and produces with a large frequency values below the confidence interval for the mean (Fig 1B).

Considering the high variability of wood and wooden materials, this strategy is suitable for the design and fire protection.

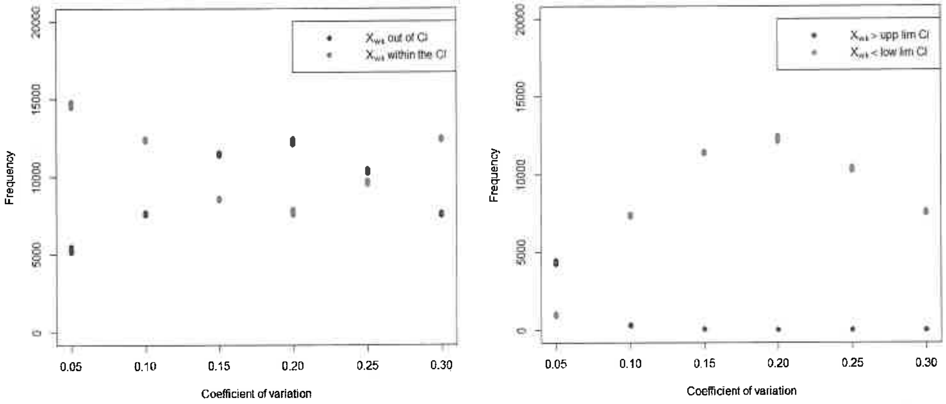

Fig. 1 - A: Frequency the location of characteristic values X_{wk} related to the confidence interval of the average. B: Characterization of the characteristic values X_{wk} located outside the confidence interval of the average

An anomalous and dangerous behavior is observed when the coefficient of variation is the smallest of all: about a quarter of the estimates of the characteristic values are greater than the upper limit of the confidence interval (Fig 1B). This study needs further development but shows another problem with the use of the standard as experimental protocol. The use of improper procedures may invalidate the very large investment that is made by some timber industries in quality control.

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PAPER REF: 5742

LATERAL TORSIONAL STABILITY OF TIMBER BEAMS

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ABSTRACT

Lateral torsional stability of timber beams with monosymmetric cross-sections. Proposals (Baláž, Koleková, 2000) are given for approximate formulae enabling to compute the values of elastic critical moments M_{cr} of beams under different loadings and various boundary conditions. These formulae were accepted by EN 1999-1-1 for design of aluminium structures and are used also for design of steel structures. It is shown that they could be used for design of timber structures too, to unify different Eurocodes procedures.

Keywords: timber, critical bending moment, lateral torsional stability.

INTRODUCTION

A beam bent about major axis in its stiffer principal plane may buckle out of that plane by deflecting laterally and twisting. Eurocode EN 1995-1-1 requires to verify the resistance of timber beam as follows

$$\sigma_{m,d} \leq k_{crit} f_{m,d} , \tag{1}$$

where $\sigma_{m,d}$ is the design bending stress, $f_{m,d}$ is the corresponding design bending strength, k_{crit} depends on the relative slenderness for bending (see EN 1995-1-1)

$$\lambda_{rel,m} = \sqrt{\frac{f_{m,k}}{\sigma_{m,crit}}} \tag{2}$$

where $f_{m,k}$ is corresponding characteristic bending strength, $\sigma_{m,crit}$ the critical bending stress

$$\sigma_{m,crit} = \frac{M_{cr}}{W_y} \tag{3}$$

The same concept of lateral torsional verification was used in various publications, national standards, prestandard Eurocodes and their National Application Documents or in Eurocodes and their National Annexes. These procedures differ in critical moment M_{cr} calculations.

ELASTIC CRITICAL MOMENT M_{cr}

Calculation of the critical moment M_{cr} is classical problem of theory of elasticity. There are many approximate formulae for calculation of M_{cr} value. It was shown by (Hooley, Madsen, 1964), that formulae for elastic critical moment may be used also for timber beams. Today there are a lot of free available computer programs (e.g. LTBeam, ALPHAcr), which enable to compute exact value M_{cr} for any boundary conditions and any loading. National standards and Eurocodes contain: a) no formulae for computing of M_{cr} value (EN 1993-1-1), or b) limited number of approximate formulae valid only for some basic boundary conditions of beams loaded by only basic action types (EN 1995-1-1, DIN 1052), or c) general and more exact formulae for a lot of loading types and many combinations of boundary conditions (EN 1999-1-1), which were taken from (Baláž, Koleková, 2000).

Formulae defining M_{cr} value are valid for members made from any structural material. It is necessary to use corresponding material properties E, G, ν (e.g. for steel, aluminium alloys, concrete, timber). Material properties $E = E_{0.05}$ and $G = G_{0.05}$ should be used for design of timber beams. .

The value of elastic critical moment M_{cr} of the reference beam, which is characterised by:

- uniform non-warping and doubly-symmetrical cross-section,
- standard boundary conditions (the beam is simply supported on both ends in all three cases: bending in xz-plane, bending in xy-plane and in torsion), which may be expressed through the coefficients $k_y=L$, $k_z=L$, $k_w=L$, see EN 1999-1-1,
- and it is loaded by equal end moments M and ψM, $\psi = 1$ (uniform moment distribution),

is given by the simple formula:

$$M_{cr} = \frac{\pi\sqrt{EI_z GI_t}}{L} \tag{4}$$

where: I_t is the torsion constant, I_z is the second moment of area about the minor axis, L is the length of the beam between points that have lateral restraint. All other cases may be transformed in the above defined equivalent reference beam by replacing L by the effective length L_{ef}, which takes into account other influences.

The effective length L_{ef} may be defined as $L_{ef} = mL$, $L_{ef} = k_{l.ef} L$ or $L_{ef} = L / \mu_{cr}$, depending on different references.

RESULTS AND CONCLUSIONS

M_{cr} value may be calculated using formula given in EN 1999-1-1 also for timber beams

$$M_{\mathrm{cr}} = \mu_{\mathrm{cr}} \frac{\pi\sqrt{EI_{\mathrm{z}} GI_{\mathrm{t}}}}{L} \tag{5}$$

ACKNOWLEDGMENTS

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PAPER REF: 5743

TIMBER COVERED BRIDGES ON THE SLOVAK TERRITORY

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ABSTRACT

A large investigative study of the historical covered timber bridges on the Slovak territory was done by Dutko and Ferjenčík in the 1954 and 1980 and published in the sixties, seventies and eighties (Dutko, Ferjenčík, 1965; Ferjenčík, 1980). Their results enabled to the authors to identify all bridges and their details on the more than 100 photographs of unknown bridges, which are property of The Monuments Board of the Slovak Republic in Bratislava. The aim of the authors is to perform a study of all historical and modern timber covered bridges on the Slovak territory. The photographs of modern bridges on the Czech and Slovak territory may be found in (Baláž, 2014; Dušan 1984, 2000, 2011, 2012; Paulík, 2012, 2014; Pechal 2009).

Keywords: bridges, timber, historical, modern.

INTRODUCTION

The historical data about opening, destroying or reconstruction of bridges, their designers, geometry and other bridge characteristics and details were collected from archives, chronicles, owners, the oldest inhabitants, contemporary engravings, veduta paintings, photographs and various publications. It was very difficult to verify some data.

RESULTS AND CONCLUSIONS

About the year 1556 a mining settlement Švedlár was founded on the right bank of the river Hnilec. At that time a timber covered bridge was constructed to transport ore. It is not known any detail about this bridge. It is supposed therefore that the bridge in the city Zvolen over the river Hron is the oldest timber covered bridge on the Slovak territory, which is possible to see on the painting by Jan Willenberg from 1599. The length of this bridge was 25 m.

Dutko and Ferjenčík (Dutko, Ferjenčík, 1965) found that in 1954 there were only 9 bridges from 29 original timber covered bridges on the Slovak territory and in 1980 there was only 1 bridge from them, the bridge in Kluknava over river Hornád. The most bridges were built over rivers Hnilec (10), Poprad (5) and Hornád (5). The longest timber covered bridges were the 2-spans (later 5-spans) bridge in Plaveč over river Poprad from 1850 with the length 68,2 m and the 7-spans bridge in Bardejov over river Topľa from 1870, which was long 78,5 m. The largest bridge in 1954 was the Upper bridge in Gelnica over Hnilec from 1831, which served after several strengthenings more than 100 years The most advanced bridge was the bridge in Kluknava over Hornád, which after several reconstructions has survived till today.

The longest timber covered footbridge in Slovakia is today the bridge in Kolárovo over river Little Danube from 1992 and 1997 (24 m were added) with the total length 86 m. It is the longest bridge in the Central Europe in the category of all-wood timber covered bridges.

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