DOCTORAL THESIS
Mathematical models and experimental investigations of timber-concrete composite beams

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Abstract

Keywords: structural engineering, composite constructions, wood, concrete, wood-concrete beams, mathematical model, coefficient inverse problem, experimental studies, static tests, dynamic tests, long-term tests.

This doctoral thesis is dedicated to the issue of mathematical modelling and static (including creep conditions) and dynamic tests of wood-concrete composite beams.

Firstly, as part of this dissertation the author conducted thorough research of the existing knowledge regarding models and experimental studies of this type of construction systems. This has allowed to set the goals of the work resulting from the recognized gaps in the literature.

Next, the basic materials from the point of view of the subject of this dissertation were described and characterized in more detail, i.e., concrete, wood, as well as methods of constructing and bonding layers of wood-concrete composites. The work also presents the models of two-layer composite beams and methods of their designing formulated so far. On this basis, the author's own model of wood-composite beam has been introduced which, beside considering the phenomena of slip and rheological characteristics of material, also takes into account the finite stiffness of the beam layers' contact in a direction normal to its surface as well as hygrothermal impacts. In this scope, the system's rheological characteristics were described in an original way using the standard linear viscoelastic model both regarding the composite's layers as well as their contact. This constitutes the basic achievement of the dissertation in the field of theoretical considerations. In consequence, the model describes deflections and horizontal displacements of the beam layers via a system of four differential-integral equations. In turn, hygrothermal fields in the system are determined by the classic diffusion and heat equations. As part of the paper, the formulated initial-boundary problem was solved using the finite difference method where numerical integration was used to calculate the convolutions of functions appearing in the mechanical side of the problem.

This was followed by performance of the below original laboratory tests:

- static tests of wood-concrete beam with a span of 3.5 m under a cyclically increasing load until exhaustion of its load capacity with a stage measurement of deflections, slips and curvature of the layers, velocity of ultrasonic waves in the upper concrete slab and frequencies of natural vibrations,
- creep tests of 4 wooden-concrete beams with a span of 4 m with measurement of deflections, slips and curvature of the layers in a period of 2 years.

Based on the measurements obtained, the material parameters appearing in the original beam model were determined. For this purpose, coefficient inverse problems were formulated, which were based on the minimization of the objective function expressed by the sum of the relative squares of differences between the measured displacements and curvatures of the beam layers and the corresponding model output data. As a result, a very good agreement between the measured and calculated quantities was obtained. The function was minimized using the non-linear least squares method, and, in the case of rheological parameters evaluation, Tikhonov's regularization of the inverse problem was used. Moreover, for the measurements of free vibration frequencies in a cyclically loaded wood-concrete beam, their usefulness in a qualitative, non-invasive assessment of elastic degradation processes occurring in this type of construction during overloading has been demonstrated.

At the end of the work for illustrative purposes, the possible calculations possible to be conducted as part of the proposed model were presented, which can be successfully used in design practice. Among others, stress changes were determined in the layers of beams – wood and concrete, resulting from the redistribution of internal forces and humidity impacts in creeping conditions.

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