Building and Environment 97 (2016) 126–136

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Moisture content prediction of rain-exposed wood: Test and evaluation of a simple numerical model for durability applications

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ARTICLE INFO

Article history:
Received 15 September 2015
Received in revised form
14 November 2015
Accepted 29 November 2015
Available online 8 December 2015

Keywords:
Moisture content
Decay prediction
Wood
Durability

ABSTRACT

Decay prediction models are frequently used to estimate the service life of wooden components. These models require knowledge of how the material climate, i.e. moisture content and material temperature, varies over time. In the present study, the performance of a simple numerical moisture transport model was evaluated for use in decay prediction models. First, a model based on Fick's second law of diffusion was calibrated against laboratory measurements where wooden boards were exposed to artificial rain. Second, the model was tested against field-test measurements on wooden boards exposed outdoors above-ground. The influence of rain was investigated by studying the difference between sheltered and exposed specimens over time. Finally, the model was applied to a number of Swedish climates and two different decay-prediction models were used to evaluate the decay rate. The influence of rain on the moisture content in wooden specimens was reproduced with sufficient accuracy for decay prediction. The error between the numerical result and the measurements tended to increase at high moisture contents and with decreasing temperature. However, the total error was reduced when the moisture content history was post-processed in a decay-prediction model as the rate of decay tends to decrease with decreasing temperature. The estimated service life varied with depth and the different decay models.

1. Introduction

As a building material, wood offers several advantages with respect to durability. Due to its natural insusceptibility to corrosion, the material has the potential to outperform both reinforced concrete and structural steel in outdoor applications. In addition, provided that chemical impregnation can be avoided, the environmental impact is low. On the other hand, in poor conditions the material degrades quickly due to fungal decay. So far, the guidance in the building codes is limited with respect to durability and service life of wood. For example, Eurocode [1] specifies that the effect of weathering should be taken into account and provides some general guidance for increased durability e.g. to avoid standing water and direct absorption between materials. However, no method to verify a target service life is given. Another example is the Swedish bridge standard, TRVK 11 [2], which specifies a minimum required level of structural protection and chemical impregnation based on the type of structure, required service life and use class. Although this type of prescriptive design format is practical, it fails to address several important decay-influencing factors such as the local climate.

A performance-based assessment based on the structure's actual climatic conditions would improve the designer's ability to make informed decisions with respect to durability design. The performance-based concept has previously been used to develop models for wooden decking and cladding where factors such as climate parameters, structural design and material properties were included [3]. The concept is illustrated in Fig. 1. An exposure model is used to link the external factors (e.g. climate and design) to the material climate which is expressed in terms of moisture content and temperature or alternatively relative humidity and temperature. Prediction models for the onset and rate of decay [4,5] then link the material climate to a service life based on the resistance of the material. In existing structures, input to decay models can be obtained from measurements. In

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http://dx.doi.org/10.1016/j.buildenv.2015.11.037
0360-1323/

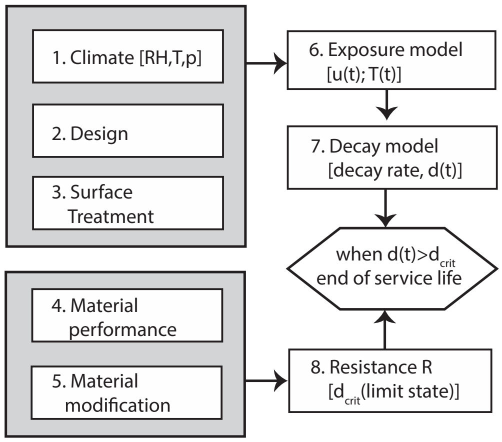

Fig. 1. Performance based concept of service life design. Items 1–5 are input data.

design situations, on the other hand, the decay models are feasible only if the input can be expressed as functions of parameters available in the design phase, i.e. external factors such as weather. Therefore, an accurate exposure model is a key when designing for durability and estimating the service life of any timber structure. The focus of the present study is on the influence of outdoor climate exposure on the moisture content in timber.

Several attempts have been made to quantify the influence of climate exposure on the service life of wood. Climate indices, which are calculated from weather parameters, have been widely used to estimate relative decay risk between climates [6,7]. However, since the climate index is not related to moisture content, it cannot be used to estimate decay rate. Some attempts have also been made to predict the moisture content in wood using regression analysis between measured moisture content data and weather parameters and use the output for decay prediction [8]. However, this type of model is usually limited to the type of data for which it was derived, e.g. the moisture content at a specific depth. In addition, the influence of rain is difficult to include in a regression model due to the time-lag between exposure and subsequent increase in moisture content [9].

Numerical models based on Fick's second law of diffusion are frequently used to calculate the moisture distributions in wooden specimens for applications such as prediction of creep [10–12] and calculation of moisture induced stresses [13,14]. However, the parameters of these models are usually limited to moisture contents below the fiber saturation point where wood is not susceptible to decay [4]. Moreover, moisture transport in the higher moisture range cannot solely be described as a diffusive phenomenon [15], although it is sometimes used as a tool for approximation.

The aim of the present study is to evaluate a simple numerical moisture transport model, based on Fick's second law of diffusion, as a tool to provide input to decay prediction models when assessing the durability of rain-exposed wood. The premise is that Fick's law can be applied with reasonable accuracy in the transverse direction during short-to medium duration rain events when the influence of capillary transport is limited. Consequently, the scope is limited to wood in use-class 3.1 situations as defined by SS-EN 335 [16], i.e. above-ground, exposed to rain and free to dry. In addition, the model is only tested for plane horizontal non-end grain rain-exposed surfaces. Exposure to rain is considered by imposing a fictitious boundary moisture content during rain events. The results of the present study are intended to be used together with subsequent research to produce a general moisture exposure model, including joints, for timber bridge applications.

The present study was carried out in three steps: calibration, verification and application of the model. In a first step (section 3), a numerical model based on Fick's second law of diffusion was calibrated against high-resolution data from a previous study on rain-exposed wood joints by Fredriksson et al. [17]. The model was then tested (section 4) in a use-class 3.1 situation by running it against field-test data presented by Isaksson and Thelandersson [3]. Special emphasis was put on the influence of rain by studying the difference between rain-exposed and sheltered boards. The moisture content on the boundary was also compared against the output from surface moisture sensors. In the final step (section 5), the model was applied to a number of typical Nordic climates. In section 5 the material climate output was post-processed using two decay-models. Fig. 2 provides a schematic illustration of the article structure.

2. Material and methods

2.1. Numerical model

The numerical model is based on Fick's second law of diffusion. In the one-dimensional case it is written as:

$$dw/dt = d/dx(D\ dw/dx) \quad (1)$$

where the diffusion coefficient, D, and the gradient of moisture concentration, dw/dx, describe the net flow of moisture, dw/dt, within the material. The diffusion coefficient is known to depend on both moisture content and temperature [18]. The moisture exchange with the ambient air which occurs on the surface can be described as [14]:

$$q = S(w_{eq} - w) \quad (2)$$

where the surface flux, q, is a function of the surface transfer coefficient, S, and the difference between the boundary moisture

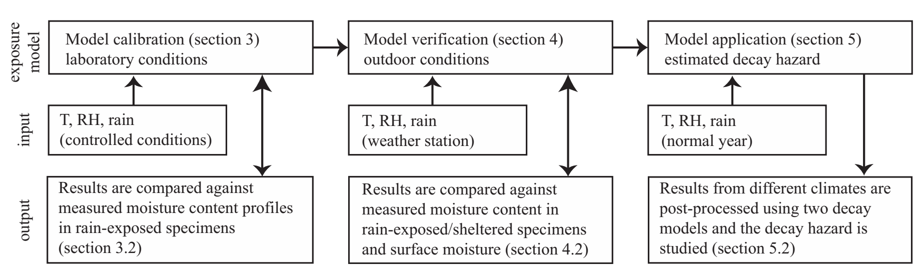

Fig. 2. Article structure. The arrows indicate the flow of information. The final step (Section 5) is an application without any additional measured data for comparison, as implied by the one-way arrow.