TECHNICAL TRANSACTIONS 6/2017
CZASOPISMO TECHNICZNE 6/2017

CIVIL ENGINEERING

DOI: 10.4467/2353737XCT.17.094.6570

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Prediction of changes in the performance characteristics of a building

Prognoza zmian właściwości użytkowych budynku

Abstract

Over the course of their use, building structures are subject to constant destructive processes, which can take various courses. Over time, performance characteristics deteriorate, and can be partially restored as a result of repair works. The article presents a proposal for the prediction of changes in the performance characteristics of a building based on the adaptation of principles applied in predicting the operational reliability of technical objects.

Keywords: degree of wear, prediction, life distribution

Streszczenie

Obiekty budowlane podczas użytkowania podlegają ciągłym procesom destrukcyjnym o zróżnicowanym przebiegu. W miarę upływu czasu następuje obniżanie właściwości użytkowych, a częściowe ich przywrócenie następuje w wyniku napraw. W artykule przedstawiona jest propozycja prognozy zmian właściwości użytkowych budynku oparta na adaptacji zasad stosowanych w prognozowaniu niezawodności eksploatacyjnej obiektów technicznych.

Słowa kluczowe: stopień zużycia, predykcja, rozkład czasu życia

1. Introduction

In accordance with the recommendations of PN-ISO 7162:1999 standards [1], an assessment of the performance characteristics of a building should be carried out, and the changes in these characteristics should also predicted over time by developing a method simulating the predicted degradation of a good over time. The set of PN-ISO standards "Planning the Service Life of a Building" [e.g. 2, 3] provides general guidelines regarding the issues of predicting the service life of a building. These standards contain an introduction to predicting performance characteristics, though without details regarding forecasting. They highlight difficulties in indicating degradation, even in the case of similar buildings, as there are many variables influencing the service lives in practice. The variety of buildings, environments, surroundings and quality of construction works, as well as future conditions of maintenance, lead to uncertainty in forecasting service life. In one of the standards [2], there is an entry stating that the course of the service life runs in accordance with the Weibull distribution and its possible modifications.

The classification of methods for predicting the service life of buildings (Predicted Service Life Distribution of the Component – PSLDC) was given by Sobotka, Bucoń [4], and comprises deterministic, probabilistic and simulation methods. Deterministic methods based on the PN-ISO standard provide merely approximated results. Probabilistic methods, on the other hand, based on indicating variables of the service model as random values with a known probability distribution, are labour-intensive. The second group of probabilistic methods for describing the course of the destruction process are methods containing Markov chains. Markov chains are often applied for describing the destruction process of bridges and technical infrastructure. Such studies are also assumed for buildings. The service process of a building structure, as a cycle containing eight operational states, was presented by Kasprowicz [5]. Another example of applying (Bucoń, Sobotka [6]) discrete Markov chains is the description of the destruction process of a residential building described in four states.

Compromise methods for determining the service life of a building, somewhere between the not very accurate deterministic methods and probabilistic methods requiring a high quantity of data, are simulation methods (according to Sobotka, Bucoń [4]), which are based on developing a mathematical model using probability distributions for determining the individual variables of the model. Studies carried out by Olearczuk [7], connected with the loss of performance abilities of buildings, provided a result in the form of a linear function of changes in the performance ability of the building.

An assessment of performance characteristics (at a specified date of service) is the matrix method, developed by a team comprising Owczarek, Orłowski, Szklennik [8] and based on the following criteria: safety of the building, safety of ecological and ergonomic service, technical conditions of service, quality of service, operational satisfaction of the owner, and realizational and operational effectiveness.

Based on the hazard, failure and disaster analyses of buildings presented by Runkiewicz [9], it turns out that most of them occur in masonry constructions (44%)

among all building technologies, and in residential buildings (41%) among all other types of buildings. Attention is drawn to the increasing needs for renovation in residential buildings by, among others, Biliński [10], Czapliński and Marcinkowska [11], Kucharska-Stasiak [12], Linczowski [13], and Skarzyński [14]. According to the author, there is a need to develop prognoses of changes in the performance characteristics of a building for the entire time it is in service. Such prognoses will be useful when panning renovation works.

2. Prognosis of changes in the performance characteristics of building components

The problem of ensuring an adequate level of the technical condition of a building occurs over the entire period it is in service. In solving problems connected with developing a prediction of changes in performance characteristics of a residential building, it is suggested to use algorithms of determining changes in the reliability of technical devices. The prognosis of unfavourable processes will make it possible to determine the time frame in which the technical condition of a building will be unsatisfactory in the future, and thus necessitate repair works. A measure of the reliability of technical devices is the $R(t)$ function, also referred to as the survival function [e.g. 15].

For modelling situations in survival analysis, when the probability of failure changes over time, the Weibull distribution is most often applied as the distribution of the random variable of the time that a building is fit for service. This distribution has been widely applied for many years as the distribution of the time of proper operation and durability of the analysed goods [eg. 16–18]. When studying changes in the performance characteristics of a residential building, when the wear of the building along with the passing of time is treated as a significant cause of failure, formulas based on the Raleigh distribution, which is a specific case of the Weibull distribution, are apt.

The PRRD model (Prediction of Reliability according to Raleigh Distribution) of changes in the performance characteristics $R_i(t)$ of the i-th building component in time t, based on the Raleigh distribution and using durability periods of component T_{Ri} from data found in literature, is described by the relationship [19]:

$$R_i(t) = \exp\left[-(t/T_{Ri})^2\right] \tag{1}$$

3. Prognosis of changes in the performance characteristics of an entire building

Each building component serves a specific task. Elements serving structural functions have the most significant influence on the service life of a building. Other auxiliary elements influence the performance characteristics of a building to a lesser degree, with their influence resulting, above all, from the fact that damaged auxiliary elements can lead to changes in the parameters of basic elements. The intensities of the influence of performance characteristics of the *i*-th components in the form of a scale of weights of elements A_i based on scale [20] serving to assess the quality of a building were accounted for when determining the performance characteristics of the entire building, which is a collection of n components.

Changes in the performance characteristics of building $R_A(t)$ in time t are determined by the relationship:

$$R_A(t) = \sum_{i=1}^{n} [A_i x R_i(t)] \tag{2}$$

4. Prediction of changes in performance characteristics of building undergoing repair works

The proposed method of predicting changes in the performance characteristics is to support activities aimed at avoiding an inadequate technical condition of a building. The effective service of a building ought to be based on maintaining an adequate level of performance characteristics of the building, while renovation processes are the means of realizing this task. All types of renovation works have a significant effect on the technical condition of a building over the course of its further use. Full characterization of a building undergoing repairs must account for the initial condition as well as changes in the performance characteristics after the completion of repair works.

Prediction of changes in the performance characteristics $R_A(t)$ of the building undergoing repairs.

$$R_M(t) = \sum_{i=1}^{s} [A_i x R_i(t)] + \sum_{i=1}^{p} [A_i \cdot k_n \cdot R_i(t - c_j)] \tag{3}$$

where:

- $R_i(t - c_i)$ – performance characteristics of *i*-th component in the c_i repair cycle,
- c_i – time building has been in service (in years) since the component was repaired.
- s – number of building components which have not been repaired,
- p – number of components in the building having undergone repairs in a given repair cycle, remaining symbols as above.

Changes in the performance characteristics of the $R_i(t - c_i)$ component can be indicated according to relationship (1) based on the PRRD model, under the assumption that repair works lead to an increase (or decrease) in the reliability of a component to the maximum value raised (or lowered) by the correction factor k_n.

5. Model system of building use

The following assumptions have been made in the proposed model of determining changes in the performance characteristics of a building undergoing repairs:

1) Repair work cycles for building components:
   c_1 = 55-year cycle – covering paint coatings of walls and ceilings, oil paint coatings of wooden elements,
   c_2 = 15 Gutters and downpipes, electrical fittings,
   c_3 = 30 wooden stairs, plumbing, plumbing fittings, gas pipes,
   c_4 = 60 wooden ceilings, roof trusses, ceramic tile roof cover, exterior plaster, doors and windows (frames), glass, floors and floor finishes, interior plaster, furnaces and radiators of central heating system, electrical wiring,
2) The times of carrying out repair words on building components result from the lifespan of these elements:
   $c_1 = 5$, $c_2 = 15$, $c_3 = 30$, $c_4 = 60$.

The recommendations regarding the times of carrying out planned preventive maintenance works were initially determined based on research and the lifespans of the building components. The proposed renovation works, which are aimed at maintaining the building in a good, satisfactory or average technical condition, rely on preventive measures and prevent the premature occurrence of unfavourable changes.

The obtained results of predictions of changes in the performance characteristics of a renovated building according to Rule (3) under the previously made assumptions have been presented in Figure 1. For comparative purposes, changes in the performance characteristics throughout the service life of an unrenovated building have been presented with a dashed line. The prediction was determined according to Formula (2).

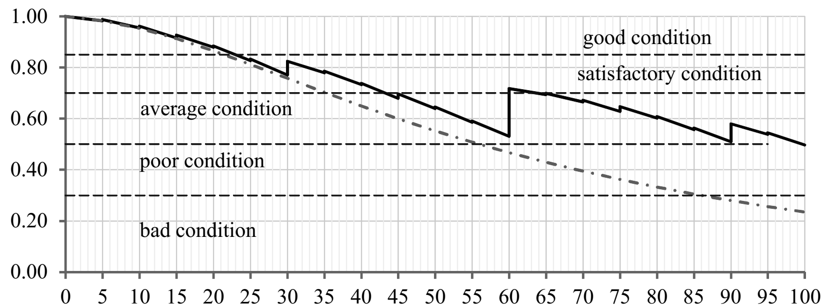

Fig. 1. Prediction of changes in the technical condition of a renovated building and unrenovated building, so-called life curve

The limits of the tolerance ranges, determined by the area of technical conditions, i.e. good, satisfactory, average and poor, have been indicated in Figure 1. The limiting values of the technical conditions were assumed in accordance with values corresponding to the degrees of technical wear.

6. Summary

The necessity to predict damage arises during all periods of the life cycle of a technical object. The prediction of the degradation of a building can be expected to be helpful in the process of reacting to damage to buildings as a result of aging. Modelling various possible scenarios of the service life of a building according to the proposed methodology will allow for the optimal planning of maintenance works.

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