26th International Conference
ENGINEERING MECHANICS 2020
Brno, Czech Republic, November 24 – 25, 2020

METHOD OF DESCRIBING THE INTENSITY OF DAMAGE IN COMPONENTS OF BUILDINGS

Nowogońska B.*

Abstract: *Buildings, during their use, are subjected to continuous destruction processes which take various courses. The article presents a picture of the changes in the technical condition of a not refurbished building constructed in traditional technology, in the form of a function describing the aging process according to the PRRD (Prediction of Reliability according to Rayleigh Distribution) model developed by the author. The results of analyses of the relationships between the function of the intensity of damage and the function of unreliability, as well as the function of changes in the performance characteristics of a building which had not undergone refurbishment during the entire course of its use are presented. Three levels of damage intensity during subsequent years of using the building were determined: safe, critical and unacceptable intensity. The presented methodology of describing changes in the intensity of damage, unreliability and performance characteristics over the course of the service life of a building is a diagnostic process of predicting the technical condition of a residential building.*

Keywords: Technical condition, Aging process, Service life.

1. Introduction

Familiarity with the course of the damage process for the entire period a building is in use is helpful when planning refurbishment works. Studies on the topic of determining the service life of a building are being carried out. Various methods, among others Markov chains (e.g. Bucoń, Sobotka 2017), are applied for the mathematical description of the course of the damage process. Problems in the aging process are also solved by neuron networks (e.g. Sztubecka et al., 2020, Ksit and Szymczak-Graczyk, 2019) or fuzzy sets (Drozd, Leśniak, 2018). The proposed model by Rivera-Gómez (2018), based on Hamilton-Jacob-Bellman equations, specified a common building, maintenance and repair strategy, minimizing the total cost in an unspecified planning horizon. The result of studies on methods of modernization works on buildings (Lacasse, 2008) is the FMEM method, which combines the use of the emergency state and effects analysis. Conclusions drawn from the methods of predicting the service life of the building can be used both at the design stage of new buildings as well as for making decisions connected with the refurbishment of buildings (e.g. Silva et al., 2016, Nowogońska, 2019). The needs of building owners in all stages of the building life cycle are also being studied (Alshubbak, 2015, Radziszewska-Zielina and Śladowski, 2017), so that the identification of needs can serve to determine the scope of building works.

The methodology proposed in the article supplements issues with a mathematic description of the aging process in the form of the relationship of the function of the intensity of damage in a building and changes in the performance characteristics of a building which had not been refurbished.

2. PRRD Model describing the aging process of a building

Buildings, during their use, are subjected to continuous destruction processes which take various courses. With the passing of time, the lowering of their performance characteristics takes place, with their partial return occurring as a result of repairs. In accordance with requirements set out by standards (PN-ISO 7162), a programme of the exposition of aging accounting for the most important mechanisms of degradation ought to be developed. The degradation model, understood as the distribution of the predicted use of a building, ought to be established accounting for the performance characteristics – time relationship,

* Beata Nowogońska, PhD, DrSc Eng Assoc. Prof.: University of Zielona Góra, Faculty of Civil Engineering, Architecture and Environmental Engineering, ul. Szafrana 1, 65-516 Zielona Góra, Poland, b.nowogonska@ib.uz.zgora.pl

doi: 10.21495/5896-3-392

applying synthetization, modelling or interpolation/extrapolation. The degradation model ought to be calculated from the performance characteristics – time relationship, by substituting quantitatively specified performance requirements, expressed in the form of performance characteristics features or degradation indicators. The relationship between performance characteristics – time ought to be a nonlinear function of time according to standards (PN-ISO 7162).

For modelling a situation in survival analysis, where the probability of a failure changes over time, as a distribution of the random variable of the time buildings are usable, the Weibull distribution is used. This distribution belongs to the family of asymmetrical gamma distributions. The Weibull distribution has been applied for many years, as a strength distribution as well as a distribution of the time of the proper operation and durability of analyzed goods (Cordeiro et al., 2013, Walpole, 1985).

After transformations, it can assume the formula describing the distribution function for the Weibull distribution. This distribution function is called the function of not survival, failure rate or unreliability function of an object F(t).

The Weibull distribution (for various parameters) creates a class of distributions covering exponential distribution as well as distributions with a monotonously increasing or decreasing function of damage intensity. Especially important in the practice of assessing goods (Cordeiro et al., 2013) is exponential distribution. In the exponential distribution, significant approximations are accepted, assuming the negligible influence of wear processes. A characteristic feature of the exponential distribution is the constant intensity of damage for entire service life of the object. The most frequently applied description of changes in the reliability of technical equipment are relationships based on this distribution. Another specific example of the Weibull distribution, where the shape parameter is α=2, is the Rayleigh distribution (Cordeiro et al., 2013). This distribution occurs when the wear of the object with the passing of time is the main reason behind failure. It is the author's opinion that the choice of the Rayleigh distribution for modelling the aging process in buildings seems to be the most accurate. All buildings and their components undergo wear over the course of their use, with the Rayleigh distribution applied in cases when the wear of the building increases along with the passing of time.

Assuming the above, it is suggested that the aging process of a building be determined by the PRRD (Prediction of Reliability according to Rayleigh Distribution) model (Nowogońska, 2014) of changes in the performance characteristics of the i-th building component based on the Rayleigh distribution. The model can be written using the following relationship (Nowogońska, 2014, 2019b):

$$R_i(t) = \exp(-\left(\frac{t}{T_i}\right)^2) \tag{1}$$

Lifespans of building components are given in literature depending on the type of applied material-structural solution.

A building is made up of many interconnected components. Each component of a building has its function. Components which serve a structural function have the most important influence on the service life. Other auxiliary components influence the performance characteristics of a building to a lesser degree, with their influence resulting, above all, from the fact that damage to auxiliary elements can lead to changes in the parameters of basic components. It was assumed that the building is constructed using traditional technology, the partition walls are masonry, made of solid brick on cement-lime mortar, the roof framework, ceilings and stairs, window frames and doors, as well as floors are all made of pine wood, the roof cover is made of ceramic roof tiles, and the plumbing from galvanized steel. For each of the 25 components, changes in the performance characteristics of the building were indicated in accordance with principle (1), and next for the entire building.

The unreliability function F(t) is described by relationship (2). Making use of the assumptions regarding the description of changes in the performance characteristics, the function of the unreliability of component i of building $F_i(t)$ in the PRRD model is expressed by the formula:

$$F_i(t) = 1 - \exp(-\left(\frac{t}{T_i}\right)^2) \tag{2}$$

3. Intensity of damage

The reliability function is described by the Wiener Equation (Nizinski, 2001):

$$R(t) = \exp(-\int_0^t \lambda(t))dt \quad (3)$$

Which disambiguates the relationships between reliability and damage intensity λ(t).

Often (e.g. Niziński, 2001 and Walpole, 1985) a different definition of the intensity of damage λ(t) is given, described as the speed at which unreliability F(t) increases in relation to reliability R(t):

$$\lambda(t)=dF(t)/dt \quad 1/(R(t)) \quad (4)$$

Using the above relationships, a formula describing the intensity of damage $\lambda_i(t)$ for building components according to the PRRD model was derived:

$$\lambda_i(t) = \frac{2t}{T_i^2} \quad (5)$$

In Fig. 1, functions of the aging process of selected building components are presented.

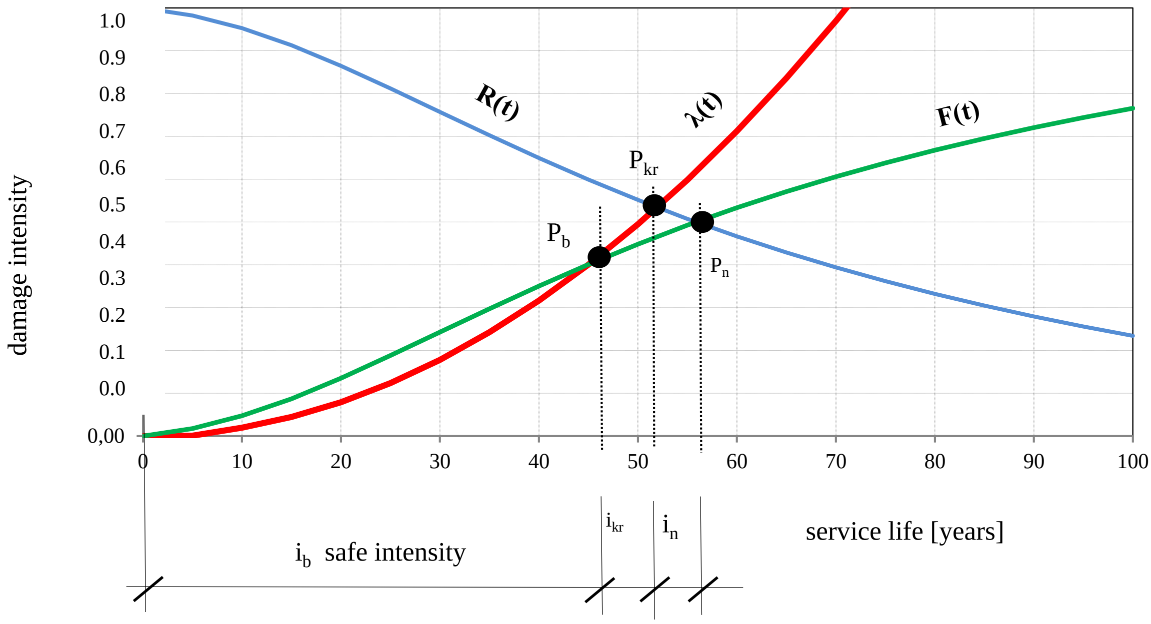

Fig. 1: Changes in the intensity of damage in an unrenovated building.

Safe intensity falls from the time a building is constructed to a term at point P_b. Point P_b implies the time when the intensity of damage to a building is higher than its unreliability. From the term P_p, the intensity of damage is assumed as critical, which increases constantly and reaches the critical level at term P_{kr}. Point P_{kr} is assumed at a term when the values of the intensities of damage are equal to the values of performance characteristics. In the following years of use, if refurbishment works are not undertaken, the intensity of damage in a building continuously increases. It is assumed that the intensity of damage reaches an unacceptable level from term P_n. Term P_n occurs when changes in the performance characteristics reach lower values than changes in the unreliability of a building. The intensity of damage of a building which had not been refurbished increases continuously over subsequent years of use. The accumulation of damage and its effects make it necessary to carry out refurbishment of the building at a term after crossing P_p.

4. Conclusions

The presented methodology of describing changes in the intensity of damage, unreliability and performance characteristics over the course of the service life of a building is a diagnostic process of predicting the technical condition of a residential building. The model of the distribution of the time during which a building operates properly presented as the prognosis of changes in the technical condition can be applied to solve problems occurring in practice.

References

Alshubbak, A., Pellicer, E., Catala, J., Teixeira, J. (2015) A Model for identifying owner's needs in the building life cycle Journal of Civil Engineering and Management 21(8), pp. 1046-1060.

Bucoń, R., Sobotka A. (2017) Decision-making model for choosing residential building repair variants, Journal of Civil Engineering and Management 21 - 7, pp. 893-901.

Cordeiro, G., Ortega, M., and Lemonte, A. (2013) The Exponential-Weibull Lifetime Distribution, Journal of Statistical Computation and Simulation 84 (12), pp. 1-15.

Drozd, W., Leśniak, A. (2018) Ecological Wall Systems as an Element of Sustainable Development—Cost Issues. Sustainability 2018, 10, 2234.

Ksit, B., Szymczak-Graczyk, A. (2019) Rare weather phenomena and the work of large-format roof coverings, Civil and Environmental Engineering Reports 2019; 3 (29), pp. 123-133.

Lacasse, M. A. (2008) Advances in service life prediction - An overview of durability and methods of service life prediction for non-structural building components, National Research Canada.

Niziński, S. (2001) Elements of diagnostics of technical objects, Publisher of University of Warmia and Mazury in Olsztyn, Olsztyn (2001) (in Polish).

Nowogońska, B. (2019a) The Method of Predicting the Extent of Changes in the Performance Characteristics of Residential Buildings. Archives of Civil Engineering 2019, 65, 81-89.

Nowogońska, B. (2014) Model of the reliability prediction of masonry walls, Engineering Mechanics 2014 - 20th international conference Svratka, Czechy. Brno University of Technology, pp. 456-459.

Nowogońska, B. (2019b) Performance characteristics of buildings in the assessment of revitalization needs, Civil and Environmental Engineering Reports 2019, 29 (1): 119-127.

Radziszewska-Zielina, E., Śladowski, G. (2017) Proposal of the Use of a Fuzzy Stochastic Network for The Preliminary Evaluation of the Feasibility of the Process of the Adaptation of a Historical Building To A Particular Form Of Use, Iop Conf. Series: Materials Science And Engineering 245, 072029.

Rivera-Gómez, H., Oscar Montaño-Arango, O., Corona-Armenta, J. R., Garnica-González, J., Hernández-Gress, E. S., Barragán-Vite, I. (2018) Production and Maintenance Planning for a Deteriorating System with Operation-Dependent Defectives Applied Sciences 165, 8.

Silva, A., de Brito, J., Gaspar, P. L. (2016) Methodologies for Service Life Prediction of Buildings, Springer International Publishing, 2016, VII, 432, 10.1007/978-3-319-33290-1.

Sztubecka, M., Skiba, M., Mrówczyńska, M., Bazan-Krzywoszańska, A. (2020) An Innovative Decision Support System to Improve the Energy Efficiency of Buildings in Urban Areas. Remote Sensing, 2020, 12, 259.

Walpole, R. E., Myers, R. H. (1985) Probability and Statistics for Engineers and Scientists, Macmillan Publishing Company, London.

PN-ISO 7162:1999 Usable requirements in construction. Content and layout of standards for the assessment of performance (in Polish).

PN-ISO 7162:1999 Service Requirements in Construction. Content and Form of Standards Regarding the Assessment of Performance Characteristics (in Polish).

PN-ISO 15686005 Buildings and Structures. Planning Service Life. Part 2. Procedures Connected with Predicting Service Life (in Polish).

PN-ISO 15686005 Buildings and Structures. Planning Service Life. Part 7. Performance evaluation for feedback of service life data from practice (in Polish).