20th International Conference
ENGINEERING MECHANICS 2014
Svratka, Czech Republic, 12 – 15 May 2014

MODEL OF THE RELIABILITY PREDICTION OF MASONRY WALLS

B. Nowogońska*

Abstract: *The suitable repair forecasting is needed for proper maintenance of the buildings. The appropriate maintenance planning should be based on the prognostic analysis of the repair needs. However, in Poland, maintenance planning is currently not seen as a long-term system. Repairs are understood as extemporary works and are carried out exclusively on the basis of intermittent inspections and controls. One of the numerous factors determining maintenance planning is exploitation reliability conditioned by durability. This article presents a proposal to determine the prediction of operational reliability of the building constructed using traditional technology. The method of behaving and changing the reliability of the building throughout its use will be useful in planning renovations. The presented analysis includes apartment buildings erected in a traditional technology and regards them as technical objects. For such approached buildings it is proposed to apply rules applied for mechanical and electrical objects. The probability of the exploitation of a building without any breakdowns in a given period of time is defined as exploitation reliability.*

Keywords: Exploitation reliability, Prediction, Degree of technical wear.

1. Introduction

The presented analysis includes apartment buildings erected in a traditional technology and regards them as technical objects. For such approached buildings it is proposed to apply rules applied for mechanical and electrical objects. The probability of the exploitation of a building without any breakdowns in a given period of time is defined as exploitation reliability.

The examined material comprises 260 residential buildings performed in the traditional technology, situated within the area of the town of Gorzow Wlkp. (Lubuskie Voivodeship in Poland). The applied building materials and the structural solutions are similar in all the buildings. The masonry walls were made of solid bricks; the floors over the ceilings – masonry, Klein type; the remaining floors – wooden beams; the stairs and the roof structure – wooden, rafter framing – purlin-collar-tie type and in some cases – collar-beam type; roofing – flat tiles or roofing paper.

The technical states of all the buildings were periodically inspected by experts. The periodic monitoring, consisting in the examination of technical wear, resulted in the reports containing the information on the percentage wear of 25 components of the buildings.

2. Methods

To model a situation for the needs of the survival analysis, when the probability changes in time, the Weibull distribution is most frequently used as a distribution of random variable of the time of the building's usefulness (Walpde and Myers, 1985; Nowak and Collins, 2000; Runkiewicz, 1998, Zaidi et al., 2012). The probability density function for the Weibull distribution is determined with the relation:

$$f(t) = \alpha \beta^{\alpha} t^{\alpha-1} \exp[-(\beta t)^{\alpha}] \qquad \text{for } t \geq 0 \qquad (1)$$

where: t -the exploitation period,
α-scale parameter (a real number) $\alpha > 0$,
β-the shape parameter (a real number), $\beta > 0$.

* Dr. Beata Nowogońska, PhD.: Institute of Building Engineering, University of Zielona Góra, ul. Prof. Z. Szafrana 1, 65-516 Zielona Góra, Poland, b.nowogonska@ib.uz.zgora.pl

Parameter α of the distribution determines the probability of a breakdown in time:

- for $\alpha < 1$ the probability of breakdown decreases in time, which suggests that, when the object breakdown is modeled, some specimen may have production defects and slowly fall out of the population,
- for $\alpha = 1$ (exponential distribution) the probability is constant, it indicates the fact that breakdowns are caused by external random events,
- for $\alpha > 1$ the probability grows in time, which suggests that time-related technical wear of elements is the main cause of breakdowns,
- for $\alpha = 2$ (the Rayleigh distribution) the probability grows linearly in time.

Distribution parameter β is a coefficient characterising the rate of the reliability obsolescence:

$$\beta = 1/ T_R \tag{2}$$

where T_R denotes the period of the object durability.

The distribution function for the Weibull distribution obtained after integration:

$$F(t) = 1 - \exp [-(\beta t)^{\alpha}] \tag{3}$$

In the literature, the distribution function is called the probability of damage, a destruction function, breakdown or a failure function and is determined with the relation:

$$F(t) = P (t< T_R) = 1 - R(t) \tag{4}$$

where: T_R - period of object durability,
$R(t)$ - reliability function, also called the probability of proper operation, or durability function.

The object's reliability is defined as the ability to fulfil the task resulting from the purpose it was intended for. It means that the object is demanded to fulfil a determined function in determined time t in determined conditions of operation. The measure of the reliability of an object, in terms of the task, is the probability of the task completing. Such determined reliability measure is a function of time of the building's reliable performance and is called reliability function.

Exponential distribution is a particular case of the Weibull's distribution, where shape parameter $\alpha = 1$. Exponential distribution is frequently used in the examination of a proper performance time (Nowogońska, 2011; Salamonowicz, 2001). The relation defining the reliability functions for the i-th component of a building for known parameters α and β may take the form:

$$R_i(t) = \exp [-(t/T_{Ri})] \tag{5}$$

where:
$R_i(t)$ - exploitation reliability for the i-th component of a building,
t - exploitation time,
T_{Ri} - durability period of the i-th element of a building.

Another particular case of Weibull distribution, where $\alpha = 2$ is the Rayleigh distribution. The application of the Rayleigh distribution for buildings seems to be the best choice. All buildings and their components are subject to technical wear and the Rayleigh distribution is applied when the object's wear increases in time. For this case, the reliability function takes the form:

$$R_i(t) = \exp [-(t/T_{Ri})^2] \tag{6}$$

2.1. Exploitation reliability of components building

To determine the exploitation reliability of a building with the use of relation (6), the building, erected in the traditional technology, was divided into 25 components. A determined material-structure solution with characteristic theoretical average durability periods T_{Ri} (T_{Ri} by Ściślewski, 1995) was assumed for each component. Relation (6) was applied to examine the change in the exploitation reliability of all the components within the assumed a 100-year period of exploitation. The selected results of calculations are presented in Figs. 1 and 2.

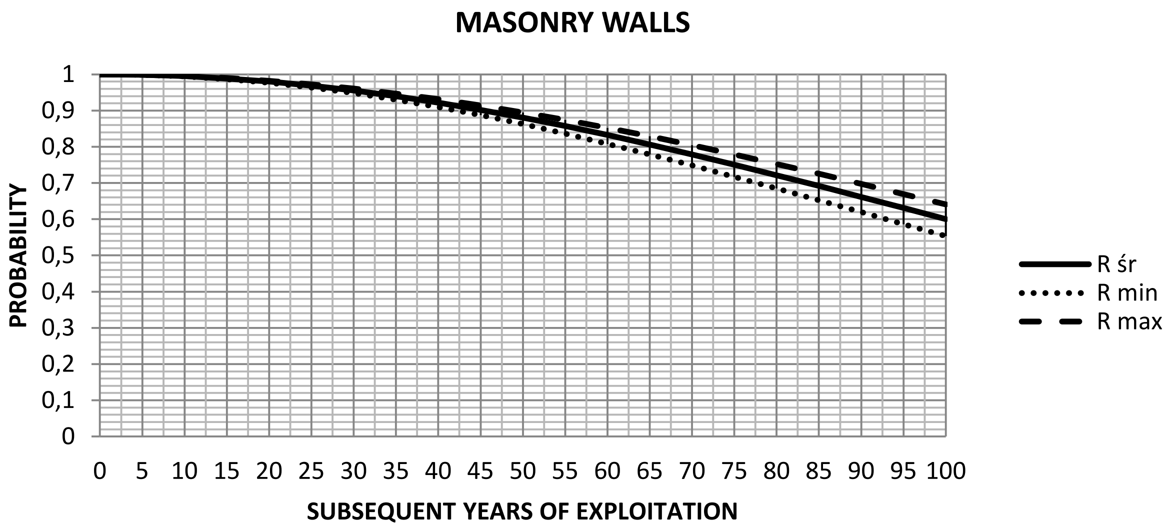

Fig. 1: Exploitation reliability of masonry walls according to the Rayleigh distribution.

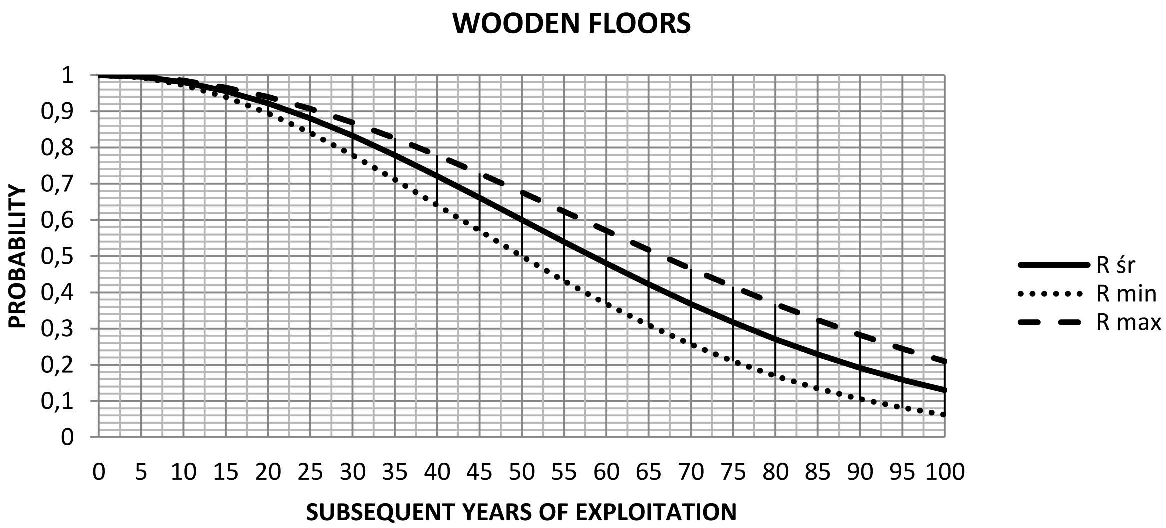

Fig. 2: Exploitation reliability of wooden floors according to the Rayleigh distribution.

Methods derived from the theory of exploitation of machines and electrical appliances were applied to examine the properties of apartment buildings. The results obtained at the present stage of the realisation of the exploitation reliability problem may be helpful in maintenance planning.

2.2. Prediction of the degree of technical wear of masonry walls

The bibliography on reliability of electronic devices attributes the intensity of failure to technical (Salamonowicz, 2001) wear as described in:

$$S_z = \int_0^t \lambda(t)\, dt \tag{7}$$

The technical wear according to the exponential distribution, where the intensity of failure is constant (7) is expressed with a linear function:

$$S_Z = t / T_R \tag{8}$$

where:

S_z – the degree of technical wear of an object expressed in percentage,
t – the age of the object,
T_R – the expected durability period of an object expressed in years.

For the Rayleigh distribution, where $\alpha = 2$, $\beta = 1/T_R$, the degree of technical wear equals:

$$S_Z = t^2 / T_R^2 \quad (9)$$

For each building element, it is possible to determine the prediction of the technical wear in any arbitrary exploitation period, the prediction of the degree of technical wear may be obtained according to the exponential distribution and the Rayleigh distribution. For brick masonry walls, the durability period is determined within the limits 130 – 150 years. The degrees of technical wear were determined for the minimum (130) and the maximum (150) values, with the use of the exponential distribution (formula 8) and according to Rayleigh distribution (formula 9). The obtained results are presented in Fig. 3.

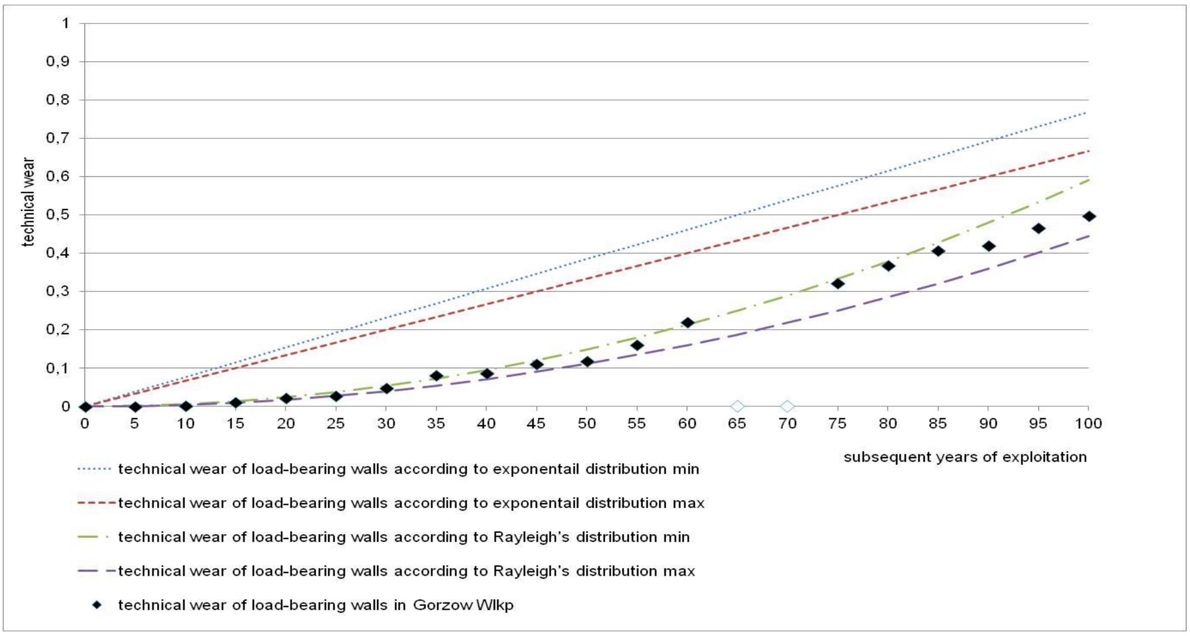

Fig. 3: Comparison between the degrees of technical wear of masonry walls according to exponential and Rayleigh distributions and the average results obtained in the evaluation.

3. Conclusions

The values of the degree of wear of the walls by the Rayleigh distribution was verified using Student t test. Assuming a 5% chance of error in applying ($p = 0.05$), and the number of degrees of freedom is 19, the critical value of the test is 2.0930. The test result in the study was 2.16817, which means that the results are statistically significant for the level of $p = 0.05$.

The results of technical wear of buildings in Gorzow Wlkp. confirm the effectiveness of the proposed method of the determination of the degree of technical wear with the use of Rayleigh distribution. The average values of the degree of technical wear determined in situ inconsiderably varied from the proposed charts in Rayleigh distribution.

References

Nowak, A. S., Collins, K. R. (2000) Reliability of Structures, Mc Graw-Hill Int. Edition.

Nowogońska, B. (2011) Reliability of building determined by the durability of its components. Civil Environmental Engineering Reports, No 6, pp. 173-180.

Runkiewicz, L. (1998) Evaluation of the quality of materials in historic buildings. In: IV Proc. of the Conference on Scientific and Technological Sciences and PZITB on "Engineering Problems of the Old Town Historic Restoration", Cracow.

Salamonowicz, T. (2001) Models reliability serviceable objects of preventive service. The Journal Issues machine operation, issue 2/2001.

Ściślewski, Z. (1995) Life building. Kielce University of Technology Press, Kielce.

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

Zaidi, A., Bouamama, B., Tagina, M. (2012) Bayesian reliability models of Weibull systems: state of the art. International Journal of Applied Mathematics and Computer Science, Vol. 22, No 3, pp. 585-600.