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RELIABILITY OF A BUILDING DETERMINED BY THE DURABILITY OF ITS COMPONENTS

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The conviction that the relation between the durability of elements and the methodology of renovation prediction is worth investigating results from the search of efficient methods of maintenance planning in buildings erected in traditional methods. 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, and determined with the rules adapted from the ones used for appliances.

Keywords: periods of element durability, determination of renovation needs, exploitation reliability, Weibull distribution

1. DURABILITY PERIODS OF BUILDING ELEMENTS

The research included the specification of building components which were first analysed separately and then together in the whole building. Each component is made of various building materials. Over time, all materials are subject to ageing and natural wear, and lose their original exploitation properties. The process is different for each building component and they are all characterised by their own durability periods.

The time of exploitation during which the components lose their exploitation properties depends on many factors: the material quality, the structure solutions, the performance quality of the building erection works, the

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influence of the environment, the way and conditions of building exploitation. The factors may occur with various frequency and intensity. Due to the complexity of the phenomena, the durability periods are the time periods of various lengths. For respective building components and solutions, average durability periods T_{Ri} may be assumed. They are values for average performance quality of the building erection works and building exploitation as well as average environmental conditions.

2. EXPLOITATION RELIABILITY

All technical objects suffer breakdowns and damages with the passage of time. The main problem arising while buildings are in use is their reliability and the endeavour to eliminate the formation of any damages.

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. For the needs of the reliability analysis of apartment buildings erected in a traditional technology, a building was divided into components which were analysed first separately and then together in the whole building. The probability of the exploitation of a building without any breakdowns in a given period of time is defined as exploitation reliability.

A complex analysis of building reliability should include phenomena accompanying long-time exploitation of a building. The following criteria are used for the reliability estimation: the wear, the frequency of maintenance works, the way of exploitation, the influence of external factors, the propriety of the project process, the quality of materials, the precision of the building erection works. In case of buildings older than 100 years there are no possibilities to examine the three last factors. For a long period of exploitation, it can be assumed that designing processes and erection works were performed correctly and the used materials were of high quality. It was also assumed that the way of exploitation and the influence of external factors for all buildings were on the same level, and did not condition the differences in building reliability and thus, they were neglected in the analysis.

3. MATHEMATICAL MODEL OF EXPLOITATION RELIABILITY

In the theory of reliability, the distribution of a product life-span is most frequently understood as an exponential distribution of a random variable of time of object usability and the Weilbull distribution, where the exponential distribution is a particular case of the Weilbull distribution for $\alpha = 1$.

The density of probability for the Weilbull distribution is determined by the relation:

$$f(t) = \alpha\, \beta^{\alpha}\, t^{\alpha-1} \exp[-(\beta t)^{\alpha}] \qquad \text{for } t \geq 0 \tag{1.1}$$

where: t - usability time,

α, β - scale and shape parameters $\alpha > 0$, $\beta > 0$.

The distribution function for the Weilbull distribution obtained after integration:

$$F(t) = 1 - \exp[-(\beta t)^{\alpha}] \tag{1.2}$$

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:

$$F(t) = P\,(t < T_R) = 1 - R(t) \tag{1.3}$$

where: T_R - period of object durability,

$R(t)$ - reliability function, also called the probability of proper operation, or durability function.

Inefficient or failure-free operations are opposite events which exclude one another, therefore relation (1.3) may be applied.

The reliability function is the change of the probability of faultlessness over time, with the Weibull density distribution:

$$R(t) = \exp[-(\beta t)^{\alpha}] \tag{1.4}$$

The intensity of damages $\lambda(t)$ is a reliability indicator, which is also defined as the intensity of the probability of damage, or the rate of growth of unreliability in relation to reliability:

$$\lambda(t) = \frac{d\ F(t)}{dt} \frac{1}{R(t)} \tag{1.5}$$

For the reliability of electric appliances the intensity of damages depends on wear:

$$S_z = \int_0^t \lambda(t)\, dt \tag{1.6}$$

where: S_z – the rate of the product wear.

To determine the intensity of damages of building components, the time method was applied to determine the theoretical wear S_Z of building components in an arbitrary time period t:

$$S_Z = \frac{t}{T_R} 100\,\% \tag{1.7}$$

where: S_z - the rate of the technical wear of an object expressed in percentage,
t - the age of an object
T_R - the expected time of object durability in years.

Formula (1.7) is applied to determine the rate of technical wear and tear of carelessly maintained buildings. Due to the negligence in the renovation-repair policy, the most unfavourable variant of the determination of the rate of wear of buildings was applied.

The result of the differentiation is the constant intensity of damages, which is a characteristic feature for the exponential distribution, thus, the Weibull distribution takes the form of an exponential distribution.

The relation defining the reliability function (1.4) for the i-th component of a building for known parameters α and β takes the form:

$$R_i(t) = \exp\,[-(t/T_{Ri})] \tag{1.8}$$

where: $R_i(t)$ - exploitation reliability for an i-th building component,
t - period of exploitation,
T_{Ri} - period of duration of an i-th component.

4. EXPLOITATION RELIABILITY

To determine the exploitation reliability of a building with the use of relation (1.8), 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} was assumed for each component.

Relation (1.8) 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 figure 1.

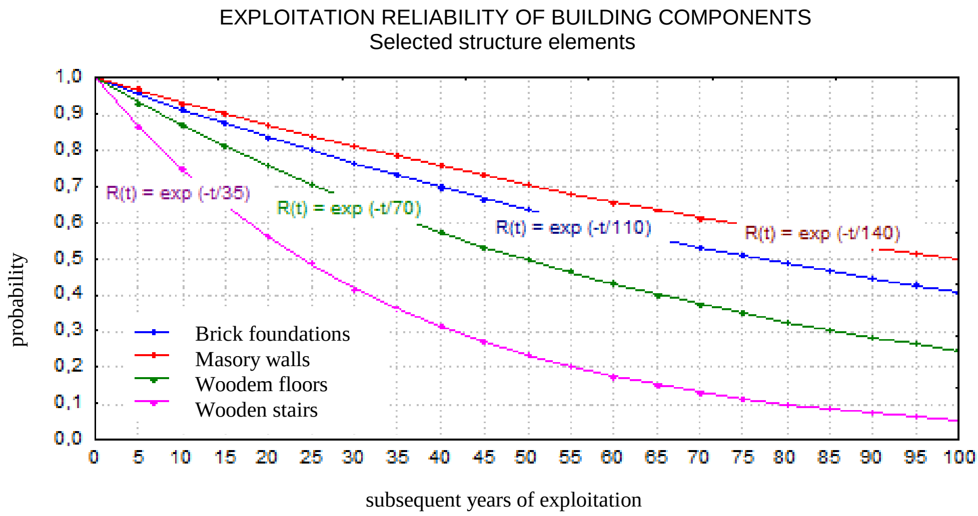

Figure 1. Exploitation reliability of structure elements

Due to the various reasons of damages to building components occurring with random intensity and frequency (e.g. the influence of atmospheric processes is different on each floor of a building; traffic intensity may cause different damages to buildings of identical structure-material solutions; similarly, different ways of building maintenance, topographic conditions; neighbouring trees and many other factors), the periods of component durability may vary considerably from the ones assumed, and thus, the change in the exploitation reliability within an exploitation period will be different. Therefore, the changes in the exploitation reliability in the subsequent years of exploitation presented in the figures should be treated as approximate.

5. APPLYING EXPLOITATION RELIABILITY FOR MAINTENANCE PLANNING

For each building component, the changes in the rate of wear and tear in a 100-year period of exploitation were examined according to the so-called time method (1.7). For the subsequent years of exploitation, it is possible to calculate the rate of wear and the probability of damage-free exploitation. The value is recognised as low when the reliability drops to the level that it is lower than its wear-out. This is the time when the repair of the component is suggested to be carried out.

Table 1. Time periods in which the renovation of particular building components should be carried out

LP	COMPONENT	TIME PERIODS FOR ESTABLISHING THE DATES OF RENOVATION WORKS	
1.	Brick foundations	63	110
2.	Masonry brick walls	80	140
3.	Masonry partition walls	57	100
4.	Wooden beam ceilings	40	70
5.	Wooden stairs	20	35
6.	Roof rafter	45	80
7.	Tail caver	40	70
8.	Gutters and drain pipes	10	18
9.	Internal plasters	32	55
10.	External plasters	26	45
11.	Windows	29	50
12.	Doors	51	90
13.	Glazing	22	40
14.	Wooden floor	28	50
15.	Wall coatings	3	4
16.	Woodwork oil coatings	3	5
17.	Cores of ceramic cookers ceramiczne	20	35
18.	Tiled stove	26	45
19.	Central heating pipes	20	35
20.	Boilers and heaters for c.h.	28	50
21.	Water supply and sewage pipes cyjne	21	38
22.	Water supply and sanitation fittings	17	30
23.	Gas pipes	21	38
24.	Electrical installations	34	60
25.	Electrical equipment	13	22

Thus, it is possible to suggest inter-repair cycles determined by dates for which the reliability is equal to the percentage wear of a given building component as well as determined by the durability periods of particular building components . The scope of work is also conditioned by the interdependence of renovation of the object’s various components. In this way, the dates of renovation have been determined for the assumed 25 building components. The obtained results are listed in table 1. They allow recognising the renovation needs for particular components during the subsequent years of building exploitation.

6. SUMMARY

The continuous degradation of buildings and the resulting high costs of repairs and renovations made the problem of optimal renovation predicting extremely important. However, in Poland, maintenance planning is not seen as a long-term system. Repairs are approached as temporarily measure, and are carried out exclusively on the basis of period controls and inspections. Additionally, there is a series of disadvantageous tendencies as far as maintenance planning is concerned. First of all, the technical needs are not fully recognised, which is accompanied by inappropriate planning of tasks and means, which is based on finance founds resulting from the assigned limits.

In order to program the repair and renovation works, the prognostic determination of the scope of work in terms of the kind and quantity is necessary. The repairs should include preventive actions aiming at assuring that no damages will occur to the building.

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.

Thus, the reliability analysis may be applied for predicting the dates of the repairs of the components of a building erected in the traditional technology. The course of the exploitation reliability of elements over the subsequent years of their exploitation may be used in prognostic planning of inter-repair cycles for the whole building.

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NIEZAWODNOŚĆ BUDYNKU DETERMINOWANA TRWAŁOŚCIĄ JEGO ELEMENTÓW

S t r e s z c z e n i e

Problem utrzymania budynków w odpowiednim stanie technicznym wymaga właściwego zaprogramowania napraw. W artykule przedstawiona jest propozycja wyznaczania niezawodności eksploatacyjnej uzależnionej trwałością elementów składowych budynku oraz jej wykorzystania do prognostycznego ustalania potrzeb remontowych.

Budynki, podobnie jak i wszystkie obiekty techniczne, wraz z upływem czasu ulegają uszkodzeniom i awariom. Podczas użytkowania każdego obiektu istotnym problemem jest zapewnienie im odpowiedniej niezawodności eksploatacyjnej. Przeprowadzona została analiza niezawodnościowa budynku z wykorzystaniem zasad stosowanych dla obiektów mechanicznych i elektrycznych. Budynek mieszkalny, wykonany w technologii tradycyjnej, potraktowany został jako obiekt techniczny. W przeprowadzonych analizach dokonano podziału budynku na elementy składowe, które najpierw odrębnie, a potem łącznie poddane zostały ocenie. W oparciu zasady teoretyczne opracowana została predykcja niezawodności eksploatacyjnej budynku.

Strategią planowania działalności remontowej budynków powinno być prognostyczne określenie zakresu robót. Znajomość przebiegu niezawodności budynku podczas całego jego okresu użytkowania przydatna będzie w programowaniu remontów.