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JAROSŁAW KONIOR*

INTENSITY OF DEFECTS IN RESIDENTIAL BUILDINGS AND THEIR TECHNICAL WEAR

INTENSYWNOŚĆ USZKODZEŃ OBIEKTÓW MIESZKALNYCH A ICH TECHNICZNE ZUŻYCIE

Abstract

Technical maintenance of existing buildings will be an important issue in the near future. The purpose of the research presented in this paper was to identify element deterioration in the course of maintaining residential apartments. In order to reach the research goal, the author analysed symptoms of the technical wear increase, i.e. performing the identification of mechanisms responsible the defect formation. The scope of this work required the creation of an original qualitative model for pinpointing defects and transferring this information into a quantitative one. Thus, it was possible to analyse the reason-effect phenomena 'defect – technical wear' relevant to the most important elements make an assessment of such an apartment block. The building in question is a block of apartment houses in Wrocław. The information gathered should prove indispensable for housing management and other such organisations involved with technical building services, as it can serve to influence the maintenance quality level of different types of existing buildings.

Keywords: building maintenance, reliability, defect, technical wear

Streszczenie

Racjonalna, systematyczna i rzetelnie przeprowadzana ocena stanu technicznego obiektów budowlanych stanowi podstawę do szeroko rozumianej organizacji ich technicznego utrzymania, a w szczególności do organizacji prowadzenia remontów i modernizacji o ustalonym rodzaju, wielkości i zakresie. Celem badań przedstawionych w artykule było rozpoznanie wpływu przebiegu procesów eksploatacji starych budynków mieszkalnych o konstrukcji tradycyjnej, na wielkość i intensywność zużycia ich elementów. Wyniki badań osiągnięto na drodze analizy objawów stopnia technicznego zużycia – poznania mechanizmu zjawiska powstawania uszkodzeń oraz identyfikacji wielkości i intensywności uszkodzeń elementów badanych budynków. Konsekwencją usystematyzowania najistotniejszych przyczyn wpływających na utratę właściwości użytkowych budynków mieszkalnych było utworzenie własnego modelu jakościowego i jego transformacja na model ilościowy.

Słowa kluczowe: utrzymanie budynków, niezawodność, uszkodzenie, zużycie techniczne

* Ph.D. Eng. Jarosław Konior, Department of Construction Methods and Management, Faculty of Civil Engineering, Wrocław University of Technology.

1. Introduction. Mechanism of defect formation in building elements

1.1. A building element defect − definition

Defect formation is a phenomenon where an element or a building loses serviceability, [1, 4, 6, 8, 10, 12–16]. It occurs when building elements or buildings reach the limit state. Exceeding this limit state for the following service functions of individual residential building elements reduces their service potential. Upon reaching service limit state, the element loses its various service functions and its state is then described by the reliability theory as inefficient but fit for use. Such a state only lasts until all of the functions of the element have exceeded this limit state. Then the element is no longer fit for use. Service limit state is a conventional value, which depends on assumed criteria.

1.2. Defect formation under service limit states

Stimuli causing the use limit to be exceeded state that the following functions of of an element may fail suddenly (random defect) progressively, (defect due to ageing) or they may represent enforced strain relief (progressive ageing of an element and a sudden transition to an unfit state occur together). Progressive ageing processes are chiefly caused by defects of a deterministic character (i.e. that can be predicted during a certain period of time). Random defects occur suddenly (breakdowns, catastrophes) or they may be caused by the faster wear (process faults or defects). Faults (sporadic defects) represent typical defects caused by poor workmanship or low quality building materials, or they may be due to both these reasons simultaneously. Process (chronic) defects, on the other hand, represent defects resulting from erroneous design assumptions and faulty structural and/or material solutions. Poor workmanship and incorporation of low quality materials make the problem more pronounced.

Where a technical element suffers a sporadic or a chronic defect, its individual functions reach their limit state faster. The reason for this is a significant reduction in the material resistance to the action of external stimuli. Such defects cause sudden changes in physical parameters that control the performance of the element. During a breakdown, limit values of the safety function of the element structure are exceeded, whereas during a catastrophe the parameters go beyond required values. Progressive defects result from ageing processes. Ageing involves irreversible structural alteration of materials used to construct building elements. They are related to physico-chemical reactions taking place over time as a result of destructive stimuli that act in the macro and the micro scale.

The rate of material ageing depends on the following [1, 4, 10, 12–16]:

– resistance of the material to destructive stimuli,
– intensity of destructive stimuli.

Accumulation of effects of these impacts results in structural changes in the material. The effect of these external and internal destructive processes is a decreased resistance of the material to failures occurring at various stages of exploitation. Thus, a progressive increase in wear and a loss of service properties occurs, leading first to inefficiency and next to unfitness. Exceeding the limit state of individual service functions of an element still does not imply total physical destruction of the element has occurred. Entire physical destruction (and complete technical,

social and economic wear) occurs, when major technical features, with regard to performance of service functions of the element do not meet parameters ensuring safe utilization.

2. Intensity of occurrence of defects in residential buildings as an element of reliability theory for technical objects

2.1. Reliability issue in the theory of exploitation

The issue of residential building reliability is always connected with the performance of exploitation tasks [3, 5, 7, 14, 15, 20]. The performance of such tasks in a residential building involves the proper fulfilment of certain functions by such a building, under given exploitation conditions and during a certain period of time. When this function is marked φ, building settlement conditions by χ, and the time of its settlement by t, then the task to be performed by the building can be described by an order of three [φ, χ, t]. By knowing a function to be performed by the building, one may determine such a set of requirements (ωφ) on a residential building, characterized by a number of main and auxiliary parameters pertaining to the technical-exploitation, economic and other aspects important in the process of exploitation and maintenance, that their fulfilment is the necessary and in a sufficient condition for adequate performance of the object functions (φ). A slightly simplified assumption, that the residential building in question represents a two-state object according to the theory of exploitation, i.e. it may be fit for its function (assuming the actual state characterized by fulfilment of requirements (ω φ), or unfit for performance of this function assuming physical state, by not meeting these requirements (ω φ). Then, the object tasks understood as an event (*Z*) (e.g. with regard to the provision of residential services) are presented as a the following ordered three: [ω φ, χ, *t*]. It was further assumed that both the requirements of a residential building, and conditions of its maintenance are known, i.e. that the pair [ω φ, χ] is set, as a result of which it was assumed that the reliability of residential buildings may be investigated with the function of time (*t*).

Residential building reliability was thus defined as follows: the reliability of a residential building is a property with the capacity to meet requirements (ω φ) within predetermined limits under given conditions of maintenance (χ) and the time of exploitation (*t*).

3. Impact of defects in residential building elements on their technical wear

3.1. A general scheme of a cause-effect model „defect − technical wear"

A general scheme of the cause-effect model „defect − technical wear" results from a synthesis of results of visual inspection of a selected sample of tenement houses. The scheme of the model in question at a most generalized level can be presented as follows:

SYMPTOMS
[CAUSES] → [observed ←→ measured] → [EFFECTS]

or in a more detailed manner:

FACTORS	SYMPTOMS		OUTCOME
⇓↓⇓↓⇓			
what causes accelerated destruction of a residential building?	defects occurring	technical wear process taking place	what happens next to the residential building?

Fig. 1. A general scheme of the cause-effect model 'defect − technical wear of building elements'

To assess the technical condition of a randomly selected group of residential buildings and their elements, a group of experts acts at an intermediate stage of the proposed model − an analysis of observed symptoms is carried out. The causes (factors) are impossible to measure, but their impact may be taken into consideration during the assessment. As regards effects (outcome), one may distinguish between temporary effects (e.g. the loss of service values) and final effects(concerning decision on the future of a residential building). Further courses of action depend on the assumption of one of methods of multi-criteria decision making, e.g. as per [7]. Greater diligence and reliability of investigations of symptoms of residential building element deterioration carried out in the observed states results in more reliable premises for the further decision-making analysis.

3.2. A method to associate defects with the process of technical wear of residential building elements

3.2.1. A point biserial correlation coefficient as an indicator of various properties correlation

At the visual assessment stage, the extent of defects which could be found in tenement houses in a town centre included identification of two types of variables:

- Non-measurable – qualitative variables, i.e. individual defects present u_{ij},
- Measurable – quantitative variables, i.e. a degree of the technical wear of individual elements z_i.

The descriptive analysis and analysis of definitions of defects occurring in the apartment houses performed as a system analysis of 'conventional' sets does not allow for considering them as measurable variables at this stage of investigation. A major drawback of the method used by experts in the assessment of the technical condition of apartment houses was found in the fact that it did not express the magnitude (strength) of defects numerically. Even when the technical documentation was reconstructed with the best intentions and a review survey was performed, it was still not possible to distinguish between a measurable value of e.g. 'significant corrosion' of steel beams of stairs and 'strong corrosion' of an element, and between e.g. 'strong wear out' of electrical wiring systems from 'strong wear out' of another element. With this level of definition imprecision, elementary defect magnitude $u_{ij,}$ a decision

was made to determine the occurrence (or absence) of a defect in the binary system $\{u_j\} = [0, 1]$, i.e. to make an assumption that the defect of a building element – identified at the basic stage – represents a dichotomous variable.

After the types of variables z_i and u_{ij} had been defined, an attempt was made at the numerical expression of relationship (should such relationships exist) between them, i.e. an attempt at measuring the influence of occurring defects of a building on the extent of the technical wear process of these buildings. In the calculation of the strength of this relationship, the method of determination of the point biserial correlation coefficient (generally marked as $r(Z)$) for the measurable property z_i and the dichotomous property u_{ij}, was used. This is one of a few cases in the statistics when properties of various types are being correlated [5, 7]. The coefficient of correlation value falls within an interval [–1, 1]. In the sets of defects U for each elementary defect $u_{ij} = u_i$ (when $j = 1, 2, \ldots, m$) and the technical wear Z, the following was determined:

- u_i – dichotomous variable that takes on values 0 (u_{i0}) or 1 (u_i1); $i = 1, 2, \ldots, n$;
- u_0 – number of observations of the variable u_i marked as 0;
- u_1 – number of observations of the variable u_i marked as 1;

apparently $u = u_0 + u_1$ (if by u, one shall understand the number of all observations u_i), and:

- z_i – measurable variable; values of this variable were divided into two groups distinguished on this basis: whether u_j takes values 0 or 1; $i = 1,2, \ldots, n$;
- z_{i0} – value of the property z_i for these units 'i', for which the property u_{i0} occurs;
- z_{i1} – value of the property z_i for these units 'i', for which them property u_{i1} occurs.

Next, arithmetic averages were calculated in the both groups:

$$\overline{z_0} = \frac{1}{u_0} \sum_{i=1}^{u_0} z_{i0} \tag{3.2.1}$$

$$\overline{z_1} = \frac{1}{u_1} \sum_{i=1}^{u_1} z_{i1} \tag{3.2.2}$$

the standard deviation (determined for the correlation $r(Z)$ with a relationship defined in a different way):

$$d(Z) = \sqrt{\frac{u \sum_{i=1}^{u} z_i^2 - (\sum_{i=1}^{u} z_i)^2}{u(u-1)}} \tag{3.2.3}$$

and as a result, on the basis of (3.2.1 – 3), the point biserial correlation coefficient $r(Z)$:

$$r(Z) = \frac{\overline{z_1} - \overline{z_0}}{d(Z)} \sqrt{\frac{u_1 u_0}{u(u-1)}} \tag{3.2.4}$$

The method of associating of defects in elements of buildings with their technical wear shown above, makes it possible to determine the direction and the strength of this relationship was used in the investigation of the influence of the defects present on the process of the technical wear in the following stages of apartment houses inspection:

- the observed state, where the correlation coefficient was calculated in all five classes of apartment houses technical wear $r(Z) = r(Ze)$ and separately in each of three medium states of maintenance of apartment houses $r(Ze)$II, $r(Ze)$III, $r(Ze)$IV;
- the theoretical state, where the correlation coefficient was determined for technical wear calculated in the classes I –V with the use of time formulas and a bi variant assumption of the expected life T of building elements:
- quoted in literature [13] $T^* = T$(Thierry), $r(Z) = r(Zt^*)$;
- maximum $T^{**} = t_{max}$, $r(Z) = r(Zt^{**})$.

Values of point biserial correlation coefficients calculated in this way for the 10 selected building elements were presented in the description of their defects, characterised by theoretical and observed states. A numerical representation of the reason-effect relationship 'defect – technical wear' contained in them was supplemented with calculated differences of the average value 'DE' of those values of the technical wear Ze, Zt^* and Zt^{**}, for which $u_1 = 0$ and $u_i = 1$. In the tables comprising of results from the author's own investigations of theoretical and observed conventional states, values of probabilities $p(u)$II, $p(u)$III, $p(u)$IV of occurrence of defects of the elements analysed in the whole sample are also presented.

3.2.2. Testing of significance of the point biserial correlation coefficient in a sample with a recognized value

Analysis of reason–effects relationships 'defect – technical wear' presented collectively for 10 selected elements of buildings, points to a considerable range of strength of these relationships within the same type of elementary defect $u_1 - u_{30}$ (Tab. 3.2). In order to compare the scope of the change in correlation to the defects and of the technical wear with the direction of change of the intervals of partial probabilities $p(u)$II, $p(u)$III, $p(u)$IV they were presented in one table (Tab. 3.2), where values of associations of the defects that present the strongest correlation (i.e. $r(Z) > 0.5$) with the technical wear were highlighted.

Due to such a great dispersion in the relationship between the measurable variable z_i and the dichotomous variable u_i the author decided to test the significance of this correlation in a sample, carrying out from 95 to 102 measurements for 10 selected elements of apartment houses. The test of significance of the correlation coefficient $r(Z)$ was performed, as in the case of the *Pearson and the Spearman* tests [2, 9] with the use of the Student's t statistics, defined in the following manner:

$$t = r(Z)\sqrt{\frac{u-2}{1-[r(Z)]^2}} \tag{3.2.5}$$

with the number of degrees of freedom $d_f = u - 2$. As a result, a precise probability $p(r)$ was calculated through the obtaining of such a value of the t statistics, as the with the one obtained on the basis of the representative sample, with an assumption that the null hypothesis H_0 ($r(Z) = 0$) was against the alternative hypothesis H_1 ($r(Z) \neq 0$) and with the determination of the two-sided criterion region. The probability $p(r)$ corresponds to the significance level observed. In the case of the linking of various properties, it should not be an error to accept a significance level of 10%. In order, however, to decisively single out those types of defect that have the strongest influence on the level of building element technical wear, an assumption was made that if $p(r) < 0.05$ then if the correlation tested is indeed significant, whereas

if $0.05 \leq p(r) < 0.10$ then one may regard this as a tendency towards the relationship sought after. Table 3.2. lists values of point biserial coefficients of association $r(Z)$. Highlighted are those that show the strongest correlation (at the significance level of 5%) and those that show a tendency towards the relationship between the defects occurring and the extent of elements technical wear of the apartment houses.

3.2.3. Extrapolation of results for the sample onto a homogenous population of tenement houses

All the samples of the 10 selected elements used in the tenement houses in question represent large statistical samples ($u > 30$), and comprise of between 15.8% and 17.0% of the parent population of 600 buildings. Approximation of the normal distribution $N(0, 1)$ was used to extrapolate results for the sample defined in this manner on the entire population and to determine confidence intervals for the point biserial correlation coefficient in the parent population. It was assumed that each of the confidence intervals will cover the true value of r (being an estimator within the population of a correlation coefficient calculated from the sample), with probability $1 - p(r) = 0.95$. For the value of the cumulative distribution function $\Phi(x) = 0.95$ in a normal distribution with the average of 0 and the standard deviation of 1, the value of statistics in this case amounted to $x = 1.96$. The correlation coefficient $g(Z)$ in the parent population is determined by the lower and the upper limit of the confidence interval in the following dependence [9]:

$$r(Z)_d < g(Z) < r(Z)_g \tag{3.2.6}$$

that is:

$$r(Z) - x\frac{1-[r(Z)]^2}{\sqrt{u}} < g(Z) < r(Z) + x\frac{1-[r(Z)]^2}{\sqrt{u}} \tag{3.2.7}$$

It was also assumed that the square of estimator $r(Z)$ corresponds to such a percentage of the parent population, for which the data obtained can be considered at a confidence level of 95%. Confidence intervals were determined, between which coefficients of correlation between the defect of elements of buildings analysed and their technical wear in the parent population and its size were determined, while distinguishing those whose $g(Z)$ is of at least moderate strength ($r(Z)_d > 0.45$).

4. Conclusions

4.1. Conclusions from the research of intensity of formation of defects in residential buildings on their reliability

The principle conclusion concerning the mechanism of defect occurrence in residential buildings stands for a period of the building exploitation during which the time of proper function until defect is characterized by exponential distribution (this is in fact the second and also the longest period of exploitation), an average period of failure-free work is constant at

any time. Thus, in theory, after a certain period of failure-free service, residential buildings perform their functions as do the new ones. A rational time for repair occurs after the second exploitation period is over, and before the period of sudden increase in the wear of the residential building.

The theoretical approach to the issue of intensity of formation of defects in residential buildings with regard to the change in their reliability enables the following conclusions to be drawn:

- the generally applied, standard definitions of reliability of buildings facilitate the research and interpretation of the course of exploitation processes of residential buildings,
- various reliability characteristics in which the function of defect intensity (that provides for the creation of other reliability indicators) is of crucial importance and should be used for the purpose of the comprehensive evaluation of changes in the reliability level of residential buildings,
- utilization of reliability characteristics of a residential building for the purpose of repair decision making enables development of a rational repair strategy, e.g. by allowing for the determination of repair intervals on the basis of defect intensity distributions,
- expression of the average failure-free service of the building (τ_0) by means of the reliability function $R(t)$, that defines probability with which the time of the proper exploitation of the building is longer than has been has been practically applied in the process of exploitation for the residential building and its components.

4.2. Conclusions from investigations of the influence of defects on the level of technical wear of residential buildings

The results of the reason-effect relationship 'defect – technical wear' research in a representative sample of town centre apartment houses erected with the use of traditional methods make it possible to present the following conclusions:

- the direction of the relationship is (as expected) right-hand (positive) for all 10 building elements tested but the strength of correlation between the defects detected and the technical wear shows a considerable span (between 0.00 and 0.84),
- as a rule, the strongest influence on the technical wear of elements in the tenement houses investigated is exerted by defects related to water penetration and moisture ingress (group II) – 0.54 on an average, while the correlation is significant in all cases,
- the technical condition of each of the elements investigated also show an influence of defects typical to their own constructional type with regard to the structure and material, for example:
  - no less important defects of wooden parts of the elements (floor beams, treads of stairs, roof truss, window joinery) attacked by pests (group IV) – $r(Z) \cong 0.42$,
  - mechanical defects of the structure and surface quality (group I), while the significance only really concerns those elements in which the defects mentioned here may be the reason for the increased influence of the subsequent defects (cumulative), e.g. of main walls of the basement, the above-ground structure and of the interior and exterior plasters (but not of the foundations or solid floor over the basement);
- defects observed in the loss of the initial shape of wooden elements (group III) may be regarded as insignificant; an exception is the skewing of window joinery – correlation

0.42 – in the case of which, this defect brings about a considerable loss of the usable value of the window joinery,

- The extrapolation of results of the reason-effect relationship 'defect – technical wear' research in a representative sample of town centre apartment houses onto a parent population of 600 tenement houses leads to the following general conclusions:
  - in each of the elements (except for the inter-storey wooden floors) there occurs at least one (up to three) correlation coefficient $g(Z)$, determined on the parent population, and characterized by a moderate strength of the relationship in question ($0.45 = r(Z)d < g(Z) < r(Z)g = 0.70$) or quite strong − ($0.60 = r(Z)d < g(Z) < r(Z)g = 0.80$); very strong correlation ($g(Z) > r(Z)d = 0{,}80$) was not observed,
  - as a rule, a correlation of at least moderate strength is always revealed by the defects caused by water penetration and moisture ingress (group II); only in cases of inner plasters and facades the mechanical defects of the structure and the surface of the elements can be treated as moderate and quite strong,
  - for the assumed confidence level of 95%, dependences of moderate strength can be refereed to as 34–48% of a parent population and the quite strong correlation – to 49–71%.

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