PREDICTION OF THE SERVICE LIFE OF MODERN STRUCTURES BASED ON ASSESSMENT OF CRACK RESISTANCE

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This article presents a new method for assessing the crack resistance of modern building structures using the example of predicting the service life of a critical element in a residential building. One of the key aspects of evaluating the durability of damaged structures is analyzing the dynamics of crack width changes. Measuring the crack width makes it possible to assess the degree of degradation of load-bearing elements and predict the moment of failure. The new method is based on considering a cracked, loaded structural element as a dynamic system operating in a *blow-up mode*. This assumption provides researchers with a tool to forecast the remaining service life of the construction element up to the point of uncontrolled defect development. The example provided in the article, involving the prediction of the service life of a wall partition, clearly demonstrates the effectiveness of this approach to evaluating the durability of residential buildings.

KEYWORDS

Prediction, building service life, crack resistance, crack width, blow-up mode, uncontrolled defect development, durability of residential buildings

1 INTRODUCTION

Modern building structures are subjected to various dynamic factors that, over time, may lead to the formation and development of cracks in their load-bearing elements. The primary sources of such damage include seismic activity, vibrations caused by metro operations, and dynamic effects from rail and road traffic [Baron 2016, Possan 2018]. These factors give rise to complex operating conditions for buildings, which necessitates the development of reliable methods for predicting their service life [ACI 224R-01 2001, Francois 2018, Murcinkova 2019, Rimar 2024].

A fundamental component of durability evaluation for damaged structures pertains to the analysis of crack opening dynamics [Zaborowski 2007, Michalik 2014, Olejarova 2017 & 2019]. This parameter facilitates the calculation of the degradation rate of structural elements and assists in the prediction of when the structure will reach its critical state [ISO 13822 2010, Vagaska 2021, Smeringaiova 2021, Rimar 2022].

The present work proposes an approach that models a cracked building as a dynamic system operating in blow-up mode. This regime is typical of nonlinear fracture processes where, at a certain stage, the damage growth rate increases sharply, ultimately leading to catastrophic structural failure [BS EN 1504-9 2008, Saga 2019, Schultheiss 2023].

The requirements for crack resistance in residential buildings are delineated by construction standards and norms [Eurocode 2 2024], which stipulate the permissible values for deflections, displacements, and crack widths for various structural types and materials [Flegner 2020, Kurdel 2018 & 2022, Labun 2020]. It is imperative that these norms are scrupulously adhered to during the design and construction of residential buildings in order to ensure the requisite durability and crack resistance [CEB 2020, Panda 2020, Nahornyi 2022].

The objective of this study is to formulate a methodology for predicting the service life of building structures with cracks. This will be achieved by analysing time series describing crack width changes. This approach is expected not only to assess the current damage level but also to identify early signs of critical deterioration [Sukhodub 2018 & 2019, Harnicarova 2019, Pandova 2020]. The method has two applications: firstly, it can be used for the monitoring of existing buildings; secondly, it can be used for the design of new structures that are more resistant to dynamic loads.

2 RESEARCH METHODOLOGY

Monitoring cracks in buildings located above metro lines is an important engineering task that involves timely identification of critical deformation development and ensuring safe building operation [Nekrasov 2020].

Figure 1. Crack in the wall of the building

This study implements a methodology involving regular monitoring and mathematical forecasting of the time when cracks reach their maximum allowable width.

Figure 2. Installation of a mechanical cracker "Tell-Tale"

In order to ensure continuous and accurate monitoring of the crack development dynamics, a combined approach was utilised, incorporating both mechanical and electronic measuring tools. In the initial instance, a mechanical crack gauge, designated as the "Tell-Tale", was installed across the crack.
In the second case, contact linear displacement sensors (LVDT) were connected to data acquisition devices. The configuration under consideration facilitated the automated documentation of minimal alterations in crack width, in conjunction with the digital transmission of data to a computer system.

Figure 3. Contact sensor of linear movement (LVDT)

The collection of data was conducted on a weekly basis, with subsequent adjustments made in accordance with external load intensity and deformation rate. The measurement results were then transmitted to an analytical system for predicting the time when the crack would reach its critical width.
The forecasting process was predicated on the analysis of a time series that described alterations in crack width during the observation period. The cracked wall was modelled mathematically as a dynamic system evolving in blow-up mode [Nagornyj 2016, Panda 2024, Wang 2024].
The prediction was carried out using the following algorithm:

1. A time series *A(t)* was formed, with each entry containing the date and crack width value.
2. To compare the forecast results, the time series was approximated by two analytical dependencies (1) and (2)

$$x(t) = A + (T - t)^{-\alpha} \cdot \left(B + C\cos(\omega \cdot \ln(T - t) - \varphi)\right) \quad (1)$$

$$x(t) = \frac{a_0}{2} + \sum_{k=1}^{n} \left[\begin{array}{l} a_k \cos(k \cdot \omega \cdot \ln(T - t)) \\ + b_k \sin(k \cdot \omega \cdot \ln(T - t)) \end{array} \right]. \quad (2)$$

The first component (1) was a combination of a smooth trend and a log-periodic cosine, and the second (2) was a Fourier series. As demonstrated by the extant research, this facilitated the acquisition of the boundary values of the forecast of the value of T. Formula (1) yielded the upper limit of the forecast, and (2) – the lower one.

3. By minimizing the deviation (2) between the measured series *A(t)* and this expression, the parameter *T* was determined – the moment the crack reaches its critical width.

$$\sum_{i}^{m} \left(A(t_i) - x(t_i)\right)^2 \Rightarrow \min . \quad (2)$$

The software module under consideration implements an algorithm that generates graphs of crack width changes over time. These graphs are constructed during the observation period, and the module is able to predict the time, T, at which the critical crack width will be reached.

3 EXPERIMENTAL RESULTS

3.1 Approximation by dependence (1)

Below is a typical example of how the graph of crack width changes is approximated by the predictive model curve (1).

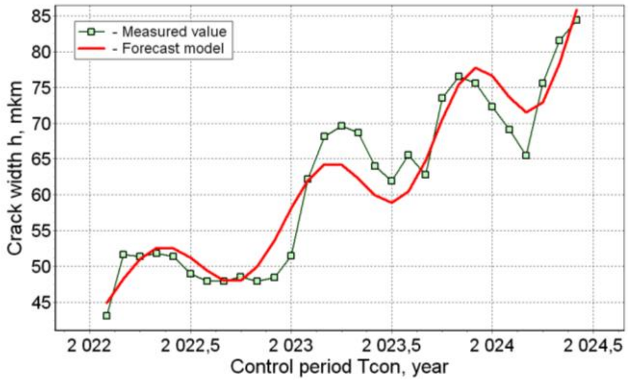

Figure 4. Approximation by forecast model (1) of recording changes in crack width

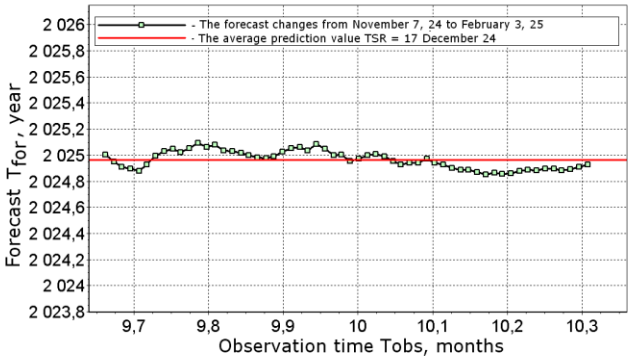

Figure 5. Forecast of the moment of reaching a critical fissure width by forecast model (1)

Additionally, the software forecasted the date when the crack width would reach the critical value.

PROTOCOL
Prediction of critical crack development
Prediction date: May 31, 2024.
Forecast:
The most probable predicted date: February 15, 2030
With confidence probability P = 0.95, the date range:
January 6, 2030 – March 25, 2030

3.1 Approximation by dependence (2)

Below is a typical example of how the graph of crack width changes is approximated by the predictive model curve (2).

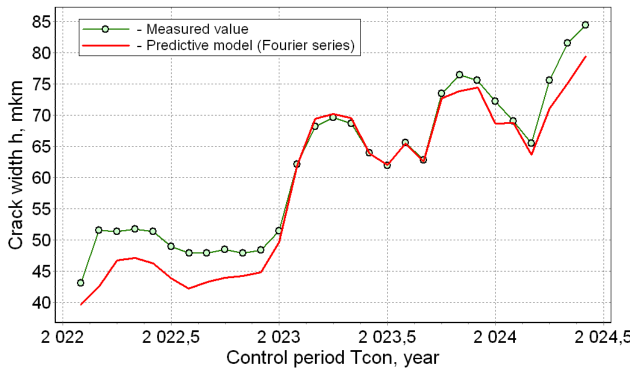

Figure 5. Approximation by forecast model (2) of recording changes in crack width

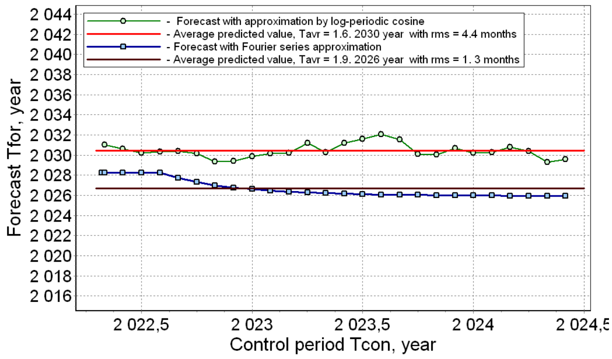

Figure 6. Comparison of forecasts made using two forecast models

Additionally, the software forecasted the date when the crack width would reach the critical value.

PROTOCOL
Prediction of critical crack development
Prediction date: May 31, 2024.
Forecast:
The most probable predicted date: December 16, 2026
With confidence probability P = 0.95, the date range:
December 11, 2026 – December 21, 2026

4 CONCLUSIONS

The buildings and structures in modern megacities, which are designed for various purposes, operate under complex conditions [Bochen 2009]. This necessitates the development of reliable methods for predicting service life.

One of the key aspects of durability assessment is analysing the dynamics of cracks opening in load-bearing elements. This parameter enables the degree of degradation to be assessed and the moment when a structure will reach its critical state to be forecast.

Therefore, a load-bearing element containing a crack should be treated as a dynamic system that develops in blow-up mode. This approach provides researchers with a means of predicting the lifespan of the element until the point of uncontrolled defect growth.

The article presents an example of forecasting the service life of a wall partition, which clearly demonstrates the effectiveness of this approach in assessing the durability of residential buildings.

Using two forecast models enabled us to obtain boundary values for the forecast, thereby increasing its reliability and validity.

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