

PETER KRUŠINSKY, PETER PISCA*

THE ANALYSIS OF NON-DESTRUCTIVE WALL CRACKS
ACTIVITY WITH THE USE OF DIGITAL PHOTOGRAPH,
IMAGE PROCESSING AND FRACTAL DIMENSIONNIENISZCZĄCE BADANIA ŚCIAN
Z ZASTOSOWANIEM FOTOGRAFII CYFROWEJ,
PRZETWARZANIA OBRAZU I FRAKTALI

Abstract

Nowadays, digital technology is being intensely developed, following its wide application, particularly to digitisation and data collection and various forms of their analysis. Rapid computer development has contributed to a rapid mathematics development, particularly in the areas of peripheral importance, for instance mathematical monsters, which subsequently have initiated new mathematical specializations, such as fractal geometry among others. Their appearance induced rapid development of other science areas, particularly data processing.

Keywords: fractal analysis, photo processing, crack breadth, accuracy analysis

Streszczenie

Dzięki bardzo intensywnemu obecnie rozwojowi technologii cyfrowej można obserwować jej szerokie zastosowanie, szczególnie w procesach zbierania i analizowania danych. Gwałtowny rozwój komputerów przyczynił się do szybkiego rozwoju matematyki, nawet w obszarach o znaczeniu peryferyjnym. W ten sposób powstały nowe specjalności matematyczne, takie jak fraktale i podobne. Rozwój matematyki pociągnął za sobą postęp w innych obszarach nauki, szczególnie w przetwarzaniu danych.

Słowa kluczowe: analiza fraktalna, przetwarzanie zdjęć, szerokość rys, analiza dokładności

* Ing. arch. Peter Krušinsky, PhD., Ing. Peter Pisca, PhD., Department of Building Engineering and Urban Planning, Faculty of Civil Engineering, University of Žilina, Slovakia.

1. Introduction

For a considerable period of time we have been examining the possibilities of fractal geometry application to building industry. Presently, we are particularly concerned with fractal analysis and employing colour depth in monitoring crack activity on buildings.

2. Source of data – digital photography

The application was facilitated by substantial progress in digital photography as well as advanced quality of the photograph – mega-pixels, optics development and optical zoom maximising accompanied by commercial availability of digital cameras. Contrary to classical photos, a digital image enables simple export to PC and an equally simple operation. Part of the photo set is the information about the current environment state and camera settings. These data facilitate adjusting the environment and defining the optimal light conditions of the environment in repeated photographing. Photography is the primary source of obtaining the final fractal dimension. To be able to be computed, the photograph has to be processed, adjusted and exported to B/W mode for the next processing. Photograph processing means surveying to make a crack and its selection clearly visible. (Fig. 1).

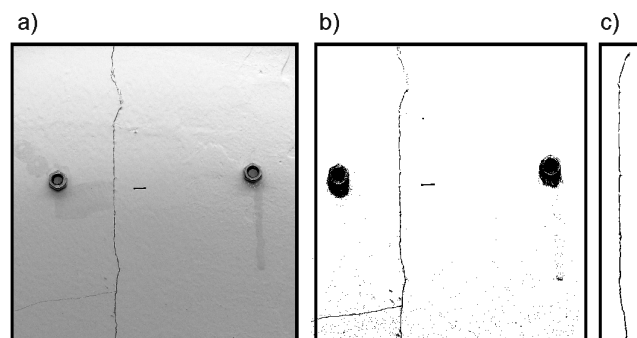


Fig. 1. Surveying to make a crack and its selection clearly visible: a) digital picture of a crack, b) disguised picture, c) selected crack in B/W mode

Rys. 1. Badania, których celem jest uzyskanie dobrego obrazu zarysowania: a) zdjęcie cyfrowe zarysowania, b) obraz zmodyfikowany, c) wybrana rysa w trybie B/W

3. Fractal geometry – fractal dimension

Fractal geometry is a separate scientific discipline which has been developed since the 1960's (B. Mandelbrot). The rate of object irregularity may be characterised by fractal geometry, or analysis. This enables us to measure the properties which are not able to be exactly quantified (e.g. rate of roughness, rate of irregularity, and so on). Fractal formations – *fractals*, are described by so called *fractal dimension*, and are considered as objects to

which it is applied, whose value of this dimension is non-integer, and is higher than the value of topological dimension

$$D \geq D_T \quad (1)$$

where:

D – fractal (non-integer, fractional) dimension,

D_T – topological (integer) dimension.

Fractal dimension is determined by the relation between a change factor of the measured quantity and a change factor of the scale. As an example we use a line segment which has non-integer dimension $D = D_T$, to which it is applied, whose $D_T = 1$. When the line segment is measured by the constantly reduced scale, the measured length is increasing and leading to the limit value. Fractal objects lack this property. When the scale is being reduced, the value isn't specified, on the contrary, the length value is constantly increasing when measuring fine details (Richardson's effect). B. Mandelbrot found out that when the scale is being constantly reduced, the measured length is constantly increasing. He gives the measuring of a shore length as a typical example, which is unlimitedly increasing in gulfs and peninsulas. New smaller gulfs and peninsulas are still being discovered, which continues into the atomic and subatomic scales.

There are numerous methods of measuring fractal dimension for 2D surfaces (e.g. box counting method, method of variance and pixels, and many others). Considering the reliability, we have chosen the box counting method. This method is mostly used to define the fractal dimension of digital patterns in B/W mode, which enables a clear definition of edges of measured objects.

4. Applying fractal dimension to monitoring crack activity

On the basis of the information briefly summarised above, we have suggested the method of monitoring the crack activity which may be considered as non-destructive. The input into the whole process of dimensional analysis is the B/W image, where the crack is selected by many operations in graphic software. Subsequently, the fractal dimension is determined by the software. This dimension characterises the crack in its primary state. In periodical, predetermined intervals, the monitored crack is digitally scanned while the same border conditions are kept. Then, the fractal dimension of the crack is computed by special software. Following the evaluation – i.e. numerisation of many photographs,

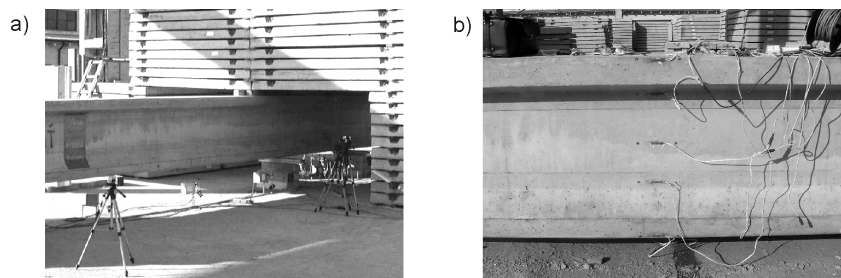


Photo 1. Weight test on bias ferro-concrete beam in PREFA Sučany:

a) digital cameras, b) tenzometers

Fot. 1. Test obciążeniowy belki żelbetowej w PREFA Sučany: a) aparaty cyfrowe, b) tensometry

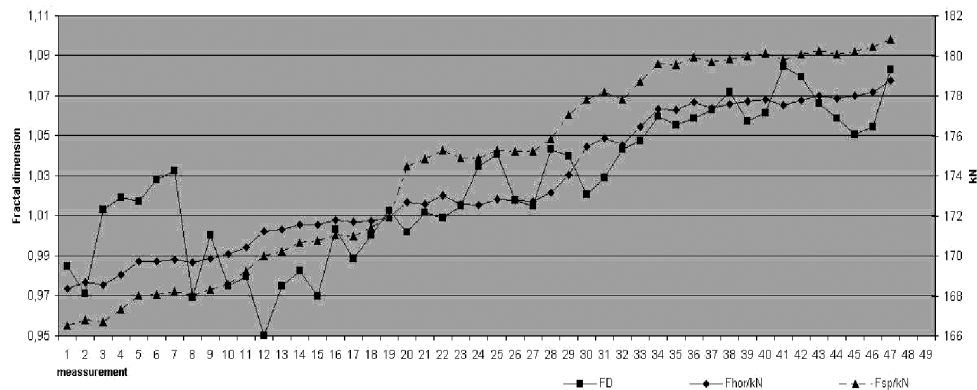


Fig. 2. Comparison of crack fractal dimension with magnetoelasticity sensing device
 Rys. 2. Porównanie rozmiarów fraktali rys z rozmiarami z czujnika magnetoelastycznego

the fractal dimensions of each single measurement are compared, and the crack activity is defined on the basis of the value changes. Nowadays, the application of other standardised methods is considered to experimentally verify the suggested principle. I would like to present some results of the methods. Typically, we perform a digital caliper measuring as a comparative method to measure the change of a crack width in buildings. We also carried out an experiment with monitoring the crack change during a weight test on a bias ferro-concrete beam, whose changes were monitored by other devices (deformeter, etc.) (Photo 1). Practicality of the method has been proved by the already conducted experiments. It is presented in the following graphs (Fig. 2).

5. Monitoring the crack activity using colour depth

Using a digital photograph it is possible to define the crack width by photogrammetry (fractal dimension is describing the crack, its change in time, not its width) (Fig. 4). Its exactitude depends on the quality of the photograph – mega-pixels, and the distance of the crack from the optics of a digital camera.

It is customary to draw the crack as a black curve in the background, as well as to monitor the crack activity with the use of colour depth. The curve is usually lighter than the crack itself and consists of a certain number of dark pixels. The number is growing as the crack is changing. By deducting the dark pixels in the cross line, we obtain the crack's width. If the etalon with the dimension specified accurately is placed (on the crack/wall), it is possible to define the pixel dimension. The number of pixels specifying the crack width also defines its width in the units of length (Photo 2). The accuracy is achieved primarily by camera parameters – its „dpi“ and zoom. Using a special programme it is possible to convert a selected part of the image into a numerical form and create a graph of the crack cross shape or its 3D model (Fig. 3). When the selected part of the image is converted into the grey range (0–255 – the basis), a numerical value is assigned to each single pixel which is processed by the method described above. The method is limited by the reciprocal rate of the crack width and the number of pixels covering the width (Figs. 3, 4).

Photo 2. Endurance testing of beam in SvF laboratory and crack selection
 Fot. 2. Test wytrzymałościowy belki w laboratorium SvF i wybór rys

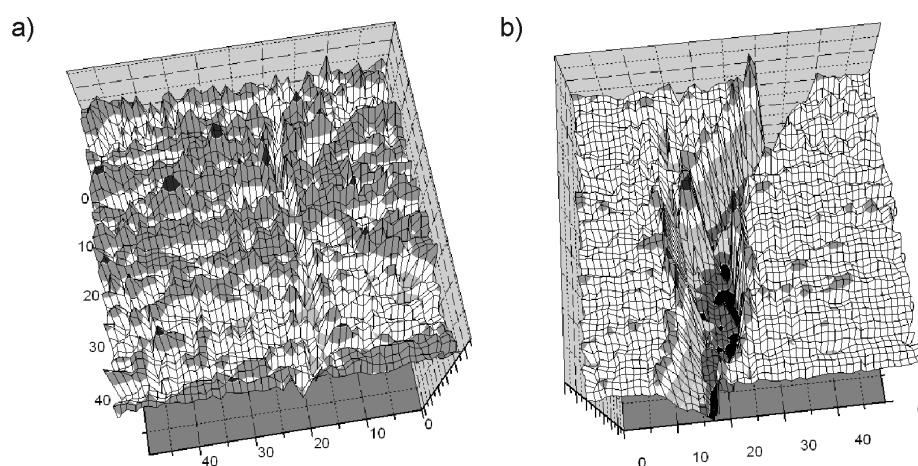
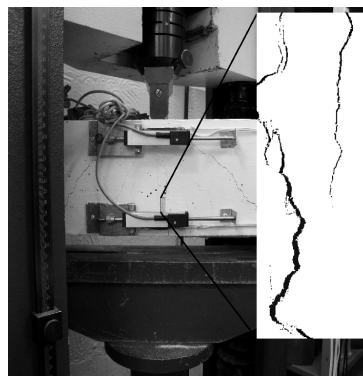


Fig. 3. 3D crack evolution: a) start evolution – 13; b) end of evolution – 64
 Rys. 3. Trójwymiarowa ewolucja rys: a) początek ewolucji – 13; b) koniec ewolucji – 64

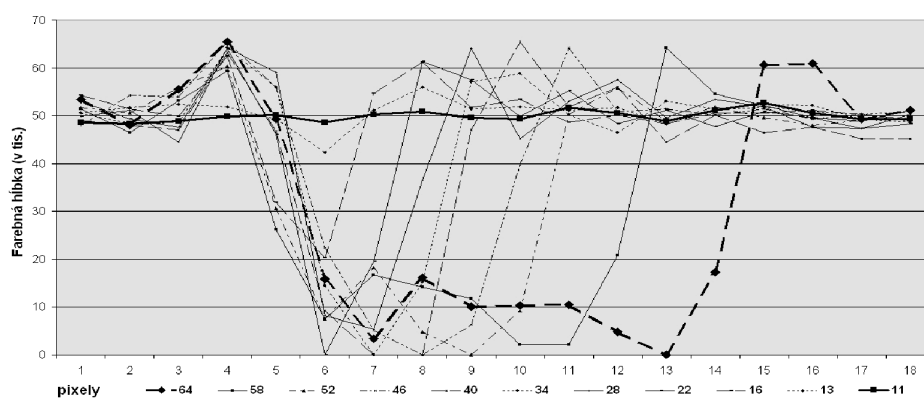


Fig. 6. Crack evolution indefined profile. Endurance testing of beam in SvF laboratory
 Rys. 6. Niezdefiniowany profil ewolucji. Test wytrzymałościowy belki w laboratorium SvF

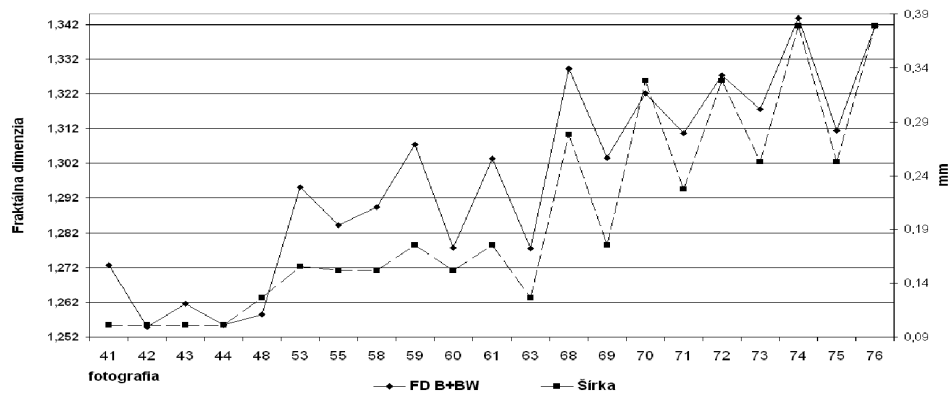


Fig. 5. Comparison of crack fractal dimension with crack width. Weight test on bias ferro-concrete beam braced with carbon lamells in VÚD laboratory

Rys. 5. Porównanie rozmiarów fraktali z szerokością rysy. Test obciążeniowy belki żelbetowej wzmocnionej taśmami węglowymi w laboratorium VÚD



Photo 3. Weight test on bias ferro-concrete beam braced with carbon lamells in VÚD laboratory
Fot. 3. Test obciążeniowy belki żelbetowej wzmocnionej taśmami węglowymi w laboratorium VÚD

6. Crack breadth determination

Analysing certain parameters, as the width and breadth of a cranny measured in pixels, one can determine its width in [mm]. The information necessary to do the calculation can be easily obtained from the datasheet of a digital camera. For example, for digital camera HP C935 the dimension of CCD sensor is 7.232×5.424 mm, i.e. 2608×1952 pixels. Using this data one can calculate the size of one pixel px

$$px = \frac{7.232}{2608} = 0.003 \text{ mm} \quad py = \frac{5.424}{1952} = 0.003 \text{ mm}$$

i.e. the size of a pixel is $3 \times 3 \mu\text{m}$.

The size of one pixel depends on focus length f and the distance between a digital camera and observed object s

$$x = px \frac{s}{f} \quad (2)$$

Digital camera HP C935 has $f = 76$ mm. If we assign to s an average distance from observer object $s = 20$ mm, then

$$x = 0.003 \text{ mm} \frac{20 \text{ m}}{76 \text{ mm}} = 0.8 \text{ mm}$$

i.e. one pixel has the size of 0.8×0.8 mm, i.e. 0.64 mm^2 .

7. Accuracy analyse

The accuracy of cranny width is estimated by function Nr 1. The following parameters have been assumed: distance $s = 20$ m, with accuracy $m_s = 2$ mm; focus length $f = 76$ mm with accuracy $m_f = 0.01$ mm; the assumed accuracy of cranny edge $m_{px} = 0.5$ px. The function of cranny width is as follows

$$\Delta d = px_2 - px_1$$

And its accuracy is

$$m_{\Delta d} = \sqrt{(m_{px_1})^2 + (m_{px_2})^2} = \sqrt{2} \cdot m_{px} = 0.7 \text{ px}$$

Cranny width in millimetres is function g

$$g(\Delta d, s, f) = x = \Delta d \frac{s}{f}$$

Applying the theory of accumulate mean error we can compute the accuracy of cranny width

$$m_x^2 = \left(\frac{\partial g(\Delta d, s, f)}{\partial \Delta d} \right)^2 m_{\Delta d}^2 + \left(\frac{\partial g(\Delta d, s, f)}{\partial s} \right)^2 m_s^2 + \left(\frac{\partial g(\Delta d, s, f)}{\partial f} \right)^2 m_f^2$$

after partial derivation

$$m_x^2 = \left(\frac{s}{f} m_{\Delta d} \right)^2 m_{\Delta d}^2 + \left(\frac{\Delta d}{f} m_{\Delta d} \right)^2 m_s^2 + \left(\frac{\Delta d, s}{f^2} m_{\Delta d} \right)^2 m_f^2 \quad (3)$$

$$m_x = 0.2 \text{ mm}$$

The second step is to estimate distance s from the digital camera to the observed object, where m_x is smaller than 0.1 mm. The function is derived from function (2)

$$s = \sqrt{\frac{m_x^2 - \left(\frac{\Delta d}{f} m_s \right)^2}{\left(\frac{m_{\Delta d}^2}{f} \right)^2 - \left(\frac{\Delta d}{f^2} m_f \right)^2}}$$

After inserting values to this function we receive the result $s = 3.9$ m. The result makes it obvious that determining the crane width with accuracy 0.1 mm necessitates the use of the digital camera zoom which is bigger than 5×.

8. Conclusion

Up to the present, there have been conducted only few crack monitorings in relatively short time. During the experiments the importance measure of simple border conditions in scanning and evaluating was indicated. There were also indicated other possibilities of crack scanning, including the subsequent data collection. Presently, there are various ways of photo processing being developed in order to achieve greater effectiveness. They are accompanied by the development of photogrammetry, as well as other methods employing information and processes of working, particularly from GIS settings and laboratories using mainly EMS.

References

- [1] Mandelbrot B., *Fraktály – Tvar, náhoda a dimenze*, Mladá Fronta, Praha 2003.
- [2] Erhardt-Ferron A., *Theory and applications of digital image processing*, University of Applied Sciences Offenburg, 2000.
- [3] Moravčík M., Zigo J., Konfál V., *Vývoj nových predpätých prefabrikovaných väzníkov v PREFA sučany*, In text book 11, Betonárske dny 2004, Hradec Králové 2004.
- [4] Krušínský P., *Metódy monitorovania aktivity trhlin*, In text book Železničné pozemné staviteľstvo 2003.
- [5] Krušínský P., *Crack monitoring*, zborník z medzinárodnej konferencie TRANSCOM 2003 v Žiline 23-25.6. 2003 sekcia 7, ŽU v Žiline 2003.
- [6] Krušínský P., *Methods of cracks monitoring*, Збірник радова: Осена станба, одржаванье и санасија грађевинских овјеката в Врњачка Банја 15-18 априла 2003, Звјаз ствебных інжнеров а техникв Јурославіе.
- [7] Bitterer L., *Vyrovňavací počet II*, <http://svf.uniza.sk/vp2/index.html>, ŽU v Žiline 2003.
- [8] Benning W., Lange J., Schwermann R., Görtz S., Chudoba R., *An algorithm for automatic analysis of deformation of reinforced concrete structures using photogrammetry*, International Symposium (NDT-CE 2003) Non-Destructive Testing in Civil Engineering, 2003.
- [9] Pisca P., Gróf V., Šíma J., *Automatizovaný monitoring zvislých posunov stavieb*, In Zb. Geotechnika, Orgware Stupava, 2004.
- [10] Krušínský P., Králiková L., *Using digital photography for cracks activity monitoring*, XIV Polish-Russian-Slovak seminar "Theoretical foundation of Civil Engineering", Warszawa-Olsztyn 30.5-2.06.2005, ŽU v EDISE.
- [11] De Schutter G., *Advanced monitoring of cracked structures using video microscope and automated image analysis*, NDT&E International 35 (2002) 209-212, 2002.