

CRACK DETECTION AT CONCRETE CONSTRUCTION UNITS FROM PHOTOGRAMMETRIC DATA USING IMAGE PROCESSING PROCEDURES

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ABSTRACT:

Cracks on the surface of a concrete construction are measured and evaluated by a digital photogrammetric method. Knowing these cracks, the behaviour of the construction, especially using textile reinforcement, can be interpreted. In the photogrammetric data the cracks are extracted by analysing the deformations. Two options are presented. On the one hand cracks are detected by searching for the maximum of strain and are followed using a list of rules. On the other hand the non-cracked areas between the cracks, which are characterized by small strains and uniform motions, are selected by a dynamic active contour method.

The project "photogrammetric measurement" is part of a collaborative research centre "textile reinforced concrete - foundation of a new technology" at the RWTH Aachen University.

1. INTRODUCTION

Concrete is a complex composite. The behaviour of a concrete construction is affected by the concrete matrix, the reinforcement and the bond between them. Strain and cracks are the external visible indications of the behaviour of a loaded construction, so that the analysis of these deformations allows an interpretation.

The measurement method photogrammetry detects deformations on the surface of concrete constructions and is used to generate the basement data of a deformation analysis. Below two methods are presented to detect cracks in the photogrammetric data. The first method follows crack structures and the second selects non-cracked areas between them to investigate cracks in a second step by a thinning method.

Subsequent the cracks are investigated to compute details like crack width or crack edge displacement.

All presented tests are realized in the collaborative research centre "textile reinforced concrete - foundation of a new technology" on the RWTH Aachen University (SFB, 1999-2006) in cooperation of the Geodetic Institute (GIA) with the Institute of Concrete Structures (IMB), the Chair of Structural Statics and Dynamics (LBB) and the Institute of Building Materials Research (IBAC).

2. MEASUREMENT TECHNIQUE AND SPECIMENS

2.1 Photogrammetry

Photogrammetry is a method to reconstruct an object using photos. The hardware of the measurement system is composed of three high resolution digital cameras (Kodak DCS Pro 14n) which take photos from different directions of a grid of targets on a concrete specimen (Figure 1 left). Before testing the

cameras are orientated by exposures of a well-known calibration element (Figure 1 right). The interior orientation (projection properties of the cameras) and the exterior orientation (position in space) are computed with a bundle adjustment. While testing the system measures periodically. In the next step the targets on the concrete construction are calculated by forward intersection. As evaluation software PHIDIAS integrated in the CAD-Software MicroStation is used (Benning, 1997). The result of the photogrammetric calculation are the coordinates of the targets at different loadsteps of the test.

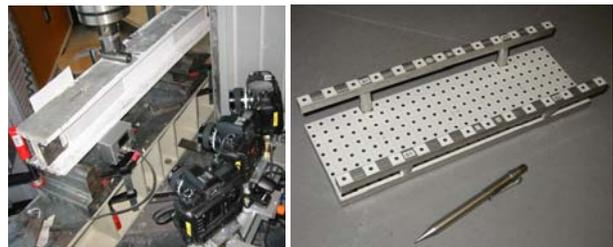


Figure 1: (left) photogrammetric experimental setup (right) calibration element for orientation of the cameras

2.2 Concrete constructions, textile reinforced concrete, crack theory

In the field of concrete structures different types of tests at concrete specimens are investigated. They can be differentiated by the types of stress, form and material as reinforcement and concrete. To use the photogrammetric measurement method the region of interest must be markable and visible for the cameras. In a test the specimen (Figure 2) is deformed by loading and its behaviour is observed. Concrete is a brittle material and cracks under a low tensile loading. The released load is transferred to

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the reinforcement, which attributes affect the form and number of the cracks.

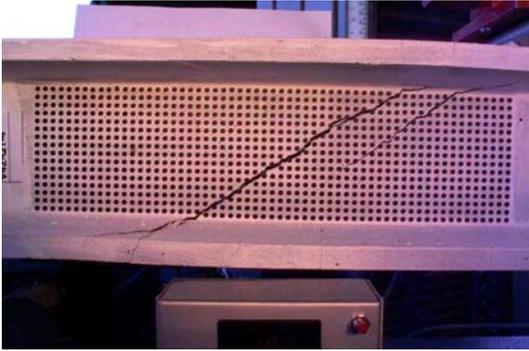


Figure 2: Specimen bending/shear test

In a special case the measurement method is used for the research at textile reinforced concrete constructions. The behaviour of the new technology is unknown and the investigation of crack pattern important for the basic research. The crack opening is an indication for load and the deformation of textile reinforcement.

Below, different methods for deformation analysis and crack detection, using digital photogrammetric measurements, are described.

3. DEFORMATION ANALYSIS AND CRACK DETECTION

3.1 Overview and pre-processing

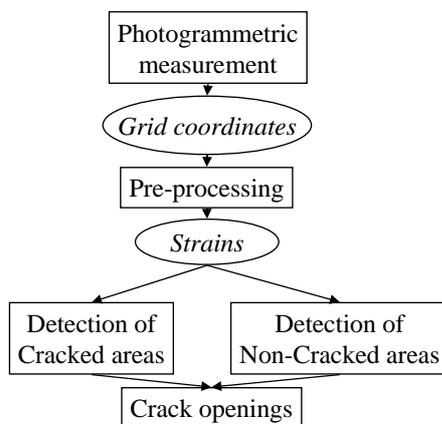


Figure 3: Overview of crack detection

From the photogrammetric measurement the coordinates of targets are known at each load step. Displacements are computed by the difference between the coordinates of the same targets in two load steps. These displacements contain the absolute movement of the construction. By the difference of the displacements between two neighbored targets the relative movements in horizontal or vertical direction are regarded. Normalized with the distance between the two targets the strains are calculated (Figure 4). The strain data is homogenized, i.e. outlier can be eliminated and missing targets interpolated.

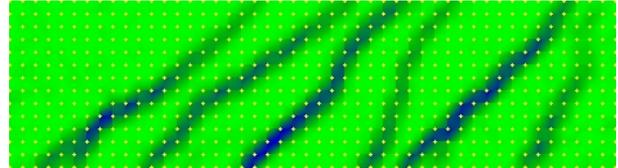


Figure 4 Strain field of a shear area in a bending test

In view of these strain patterns cracks are recognizable for the human eye. To detect high strain areas as cracks and classify them in mechanical joint cracks automatically here two opposite methods are presented. On the one hand the cracks are followed and marked and on the other hand non-cracked areas are filled and their borders are detected as cracks.

3.2 Detection of cracks based on cracked areas

The limit of strain to decide of crack existence is the tensile strength of the used concrete. Because of the noise of measurement and material as well as the possibility of closing cracks this value is really not sufficient. The investigation of the neighbourhood provides an additional criterion.

If outliers are excluded, a crack detection can start at the edge between the two measured points with the highest strain. In two directions the surrounding areas are investigated for the best way of the crack. Then iteratively the crack is traced and marked. As stop criterion the border of the measured area or another marked crack is reached or one or more matched values are less than a limit. Then the process is repeated, till all cracks are selected and the start value as the highest remaining value is less than another limit (Figure 5).

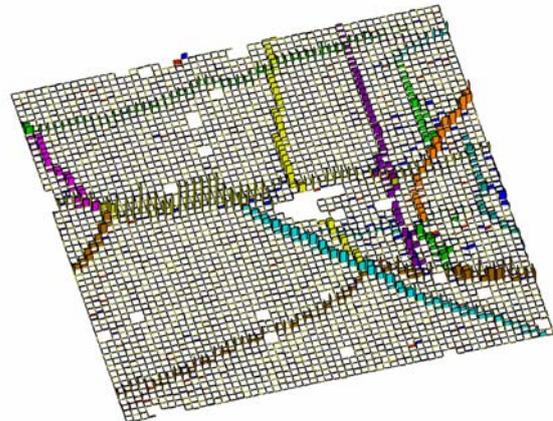


Figure 5: plate with detected cracks

Additional rules support the crack detection process.

- Crack history: If a crack exists, its crack opening can scale down, but the crack cannot lose its mechanical properties.
- Crack distance: The distance between two cracks depends on properties of concrete, reinforcement and bond. It can be estimated and used in computation.
- Crack direction: Cracks are scale invariant (Mandelbrot, 1982) and discrete, but their global direction does not change rapidly.
- Crack connection: If two cracks collide and run in the same direction they are connected.

Using this tracing method and the knowledge rules a crack pattern is detected and separated in several combined cracks. The method is stable for cracks, which are any long, any curved, any high and close together, but cannot adjust imperfections on the crack course.

3.3 Detection of cracks based on non-cracked areas

Cracks are the separation of the construction, the areas between them are contiguous in moving and strain. Their detection and computation of cracks afterwards is a different approach to understand the behaviour of the construction.

The dynamic image processing method "Active Contours" fits a mathematic contour to a curve (e.g. a crack) (Kass, 1988; Kobbelt, 2004). In a crack pattern (Figure 2) the non-cracked areas are bordered by cracks or the border of the measurement field. The concept first pre-processes the data by a static image processing method developed by Prager (Prager, 1980) and then uses active contours in form of self extracting balloons (Kobbelt, 2004).

The static image pre-processing by Prager is an iterative relaxation method to segment contours in view of neighbored displacements. The displacements between each two targets are normalized as probabilities of crack existence. The neighbored probabilities are multiplied in horizontal and vertical direction and set a new value for the tested edge. After some iterations a first crack-pattern with intensified crack areas but without knowledge of mechanical ways of cracks is computed (Figure 6). This is the base for the active contours method, described in the following.

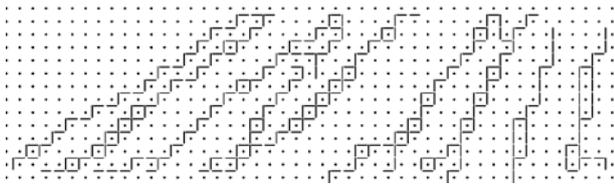


Figure 6: Neighbour-based crack detection using the method of Prager (Prager, 1980) (shear field)

Commonly the process of active contours is determined by the minimisation of the sum of an interior energy, as attribute of the mathematical representation e.g. the curving and the exterior energy, which is given by the properties of the strain field.

$$E_{snake} = E_{interior} + E_{exterior} \quad (1)$$

where E_{snake} = minimised sum of energy
 $E_{interior}$ = interior energy, e.g.: bending of curve
 $E_{exterior}$ = exterior energy, e.g.: strain field

In the described application the contour is represented by a polygon, whose vertices are self controlling elements called "snaxels". Kobbelt (Kobbelt, 2004) presents such method to extract the structure of a brain from computer tomography patterns. His method - called restricted snakes - uses a grid, which is predetermined here by the grid of targets.

The initialisation point is investigated by the results of the pre-processing. Following a section non-cracked elements are detected. If the element is unmarked, it is the start point for a new active contour polygon.

From there the contour spreads till it is terminated by a crack or a border (Figure 7).

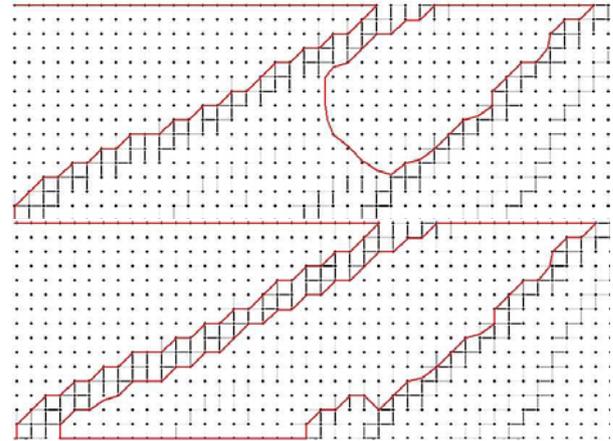
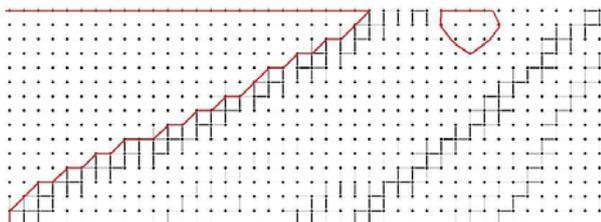


Figure 7 : Three steps of the evolution of an active contour polygon on a shear field

The snaxels move on the grid between the targets and are conform to following rules:

- On a vertex/ target the snaxel splits into each new direction
- If two snaxels collide, they freeze or merge
- The direction of snaxels is always outward of polygon contour
- The curve of contour and the properties of the strain field affect the moving of each snaxel

If all contours are terminated the best way of the cracks is detected in the corridors between the contours using a simple thinning method. The midpoint between two snaxels, which points to each other is computed and presented as curve in Figure 8.

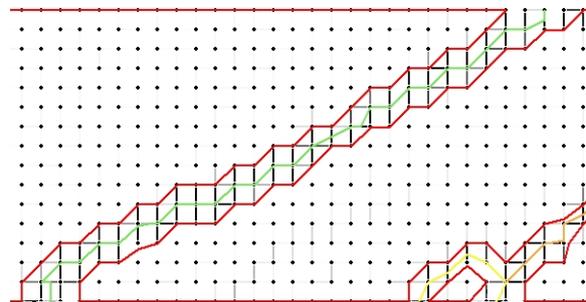


Figure 8 Cracks (grey/green) between two non-cracked areas using thinning method

The contour is insensitive to small imperfections in a crack through the calibration of the stiffness of curve. But the method is restricted to a minimum distance between two cracks. The advantage is the knowledge of the non-cracked areas as blocks.

3.4 Comparison of methods and crack analysis post-processing

The tracing method is faster and easier than the active contour method, but imperfections of the crack course can not be adjusted. A supplement method to bridge imperfections and also to compute non - cracked areas from the tracing results is possible.

Both methods are limited by the grid of targets. The results are the discrete ways of cracks (Figure 5 and Figure 8), which can be adjusted e.g. by Akima - splines (Polansky 1996). But the real crack form is scale invariant (Mandelbrot 1991) and can mathematically not be represented.

Anyway the crack openings can be computed if the targets are defined on one of the crack sides. Further on a method is presented using only four neighboured targets to calculate the crack width and the crack edge displacement. In the marked crack pattern the crack angles are determined by regression straight lines, crack width and crack edge displacement are determined according to Görtz (Görtz, 2004).

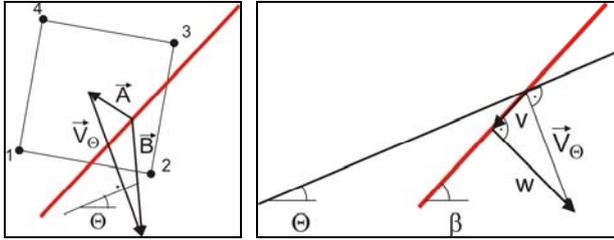


Figure 9 Calculation of crack width w and crack edge displacement v , crack opening vector \vec{V}_Θ , vertex displacements \vec{V}_1 to \vec{V}_4 , average displacements \vec{A} , \vec{B} , crack angle β

The displacements of the vertices \vec{V}_1 to \vec{V}_4 are separated by the crack. On both sides the average of the displacements is computed (\vec{A} , \vec{B}).

$$\vec{A} = (\vec{V}_1 + \vec{V}_3 + \vec{V}_4) / 3 \quad (2)$$

$$\vec{B} = \vec{V}_2$$

The difference of the average values results in the crack displacement \vec{V}_Θ , which can be converted with an available crack angle using trigonometry into crack width and crack edge displacement (Figure 9, formula 2 to 3).

$$\vec{V}_\Theta = \vec{B} - \vec{A}$$

$$w = |\vec{V}_\Theta| \cdot \cos(\beta - \Theta) \quad (3)$$

$$v = |\vec{V}_\Theta| \cdot \sin(\beta - \Theta)$$

The representation shows the entire detected crack pattern and in the detail crack width and crack edge displacement (Figure 10).

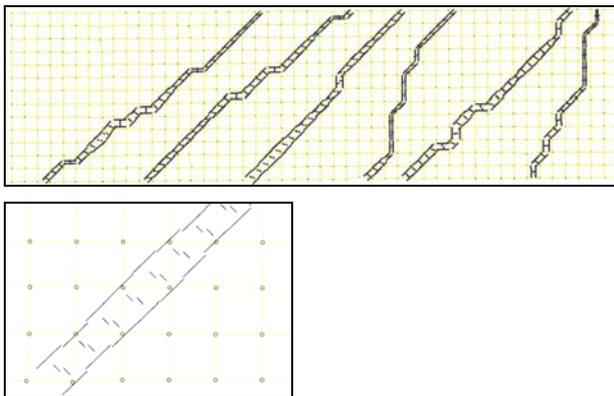


Figure 10 Crack width and crack edge displacement
a) Shear test overview
b) Detail of a)

4. ACKNOWLEDGEMENTS

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The tests are made in cooperation with the Institute of Concrete Structures (IMB), the Chair of Structural Statics and Dynamics (LBB) and the Institute of Building Materials Research (IBAC).

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