CRACK DETECTION DURING LOAD TESTS IN CIVIL ENGINEERING MATERIAL TESTING WITH DIGITAL CLOSED RANGE PHOTOGRAMMETRY – ALGORITHMS AND APPLICATIONS

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ABSTRACT:

Methods of digital photogrammetry are qualified for automatically measuring of two- and three-dimensional fields of displacements, deformations and defects such as cracks on surfaces of test objects and structures during short and long time load tests in civil engineering material testing. The first part of the paper gives a short overview on some recent research projects employing digital closed range photogrammetry in a wide range of 2-D, 2.5-D and 3-D civil engineering material testing applications. The main part of the paper describes the developed algorithms for the detection, localization and width-determination of cracks during load tests of TRC-probes (Textile Reinforced Concrete). The paper presents the requirements/boundary conditions and the results for two different test setups, for tension (2.5D) and shear tests (3D). The detected minimum crack width is approx. 5 µm in a measurement area up to 240 mm x 100 mm.

1. INTRODUCTION

An essential topic in civil engineering research is the verification of different theories and mechanical models with the reality with static, quasi-static and dynamic short and long time load tests of probes and structures. During the load test the measuring technique has to measure and register all relevant parameters such as load, strain, stress, displacements, deformation and cracks or other defects. Typical measurement techniques for measuring displacements and deformations are wire strain gauges and inductive displacement transducers. These measurement techniques supply on-line results with a high precision only in one direction and are therefore not qualified for measuring a large number of points or the detection and localization of cracks in probes and structures during load tests. For measuring tasks with a large number of measuring points or for overall measurements in short and long time, methods of digital closed range photogrammetry may be used. They offer the advantage of automatically measuring two- and three-dimensional displacement fields, deformations and defects like cracks (e.g., Fu et al., 2002; Whiteman et al., 2002; Fraser et al., 2003; Hampel et al., 2003; Riedel et al., 2003; Maas et al., 2006; Ortlepp et al., 2006; Rönnholm et al., 2009). This motivation was the reason for a number of research activities for the application of the digital closed range photogrammetry in civil engineering material testing at the Dresden University of Dresden (Hampel 2008).

2. DIGITAL CLOSED RANGE PHOTOGRAMMETRY IN CIVIL ENGINEERING MATERIAL TESTING

Planning and efficiently performing photogrammetric measurements in a wide range of civil engineering material testing tasks requires a systematic approach to the technique and the definition of task-oriented measurement concepts. In the following, we will discuss hardware configurations for photogrammetric data acquisition, methods for the application of these systems to different tasks and algorithmic aspects in the automation of whole measurement procedures in mass experiments. Each experiment can be subdivided in the tasks of planning, preparation, data acquisition and processing as well as post-processing. Defining measurement procedures for new measurement tasks, these individual steps require expert knowledge in civil engineering as well as in photogrammetry.
In context with the single measurement tasks, an open modular system (next section) was developed to realize the special measurement processes.

2.1 Digital Photogrammetry System

The developed photogrammetry system is an open modular system. The modules include all parts to realize the special measurement tasks in civil engineering material testing, e.g. the crack detection during load tests. Also, the modular system can be combined with external (commercial/proprietary) hard- and software modules to achieve efficient solutions for different measurement tasks in civil engineering material testing.
The developed modules include project management tools, data synchronization modules, control units, image acquisition modules and image- and data-processing-modules. Additional modules are available for testing and verifying of the special measurement configurations/setups or the developed modules. A detailed description of the modules you will find in (Hampel 2008). The used digital camera model for the presented experiments (Section 3) was a Kodak Megaplus 4.2i/10 (Fig. 1/2). The sensor of the Kodak Megaplus is a CCD with 2k x 2k Pixel (1-2 Hz) with a fill-factor of 100 % and a radiometric resolution of 10 bit. High precision measurements can be done with this type of camera. The methods of the developed digital photogrammetry system show a precision of up to 1/50 pixel for natural textures and up to 1/100 pixel for artificial signalizations (Hampel 2008). Also a high-speed camera FastCam Ultima (Figure 8) was used. The FastCam Ultima has a CMOS-sensor

and can acquire image sequences with a geometric resolution between 256 x 32 Pixel (16 kHz) up to 1k x 1k Pixel (0.5 kHz). This high temporal resolution is needed for detection of dynamical or crash situations (Section 3.2).

3. CRACK DETECTION

In this section were presented two types of load tests, tension tests (Section 3.1) and shear tests (Section 3.2). The load tests were realized in research projects of the COLLABORATIVE RESEARCH CENTER 528*. In this context, the intension of both photogrammetric measurement tasks was the detection of the number of cracks, the crack width and the crack position during the load tests of textile reinforced concrete probes (TRC). In case of tension tests, the deformation of the probe was typically limited to 2D (in-plane), but during the load tests the whole configuration was slightly moved in 3D (rigid body motions). This kind of effect was detected very often and therefore a special 2.5D-setup was developed (Hampel 2008). In case of shear tests, the deformation of the test body was typically in 3D (in-plane and out-of-plane). A detailed description about the algorithms of the crack-analysis you can find in (Ortlepp et al., 2006; Hampel 2008).

3.1 Tension Test (2.5-D)

The first example describes a tension test of a textile reinforced concrete probe (Lieboldt 2009). The measurement area is approx. 240 mm (Z) x 100 mm (X). Two digital cameras (Kodak Megaplus 4.2i/10) were used for the photogrammetric measurement in a 2.5D-setup (Hampel 2008). Figure 1 show the used test setup. This setup was developed for high precision 2D-measurements with rigid body motions. For the realization of 2.5D-measurements a special reference system is necessary (Figure 2).

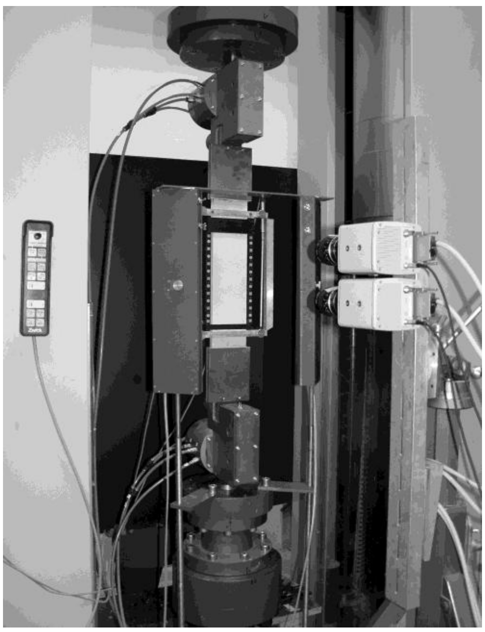

Figure 1. Test setup for tension tests (2.5D)

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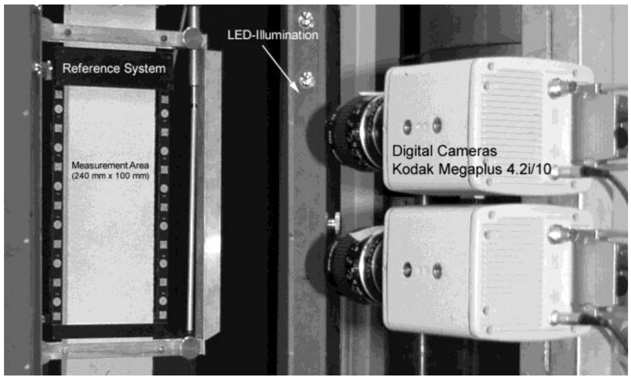

Figure 2. Test setup with reference system (2.5D)

The first results of the digital crack analysis are deformation fields for the total measurement area or/and for single measurement profiles in longitudinal direction. Figure 3 shows an example for the detected relative displacements dZ in direction of tension (Z) for one profile (Profile 5) and one load step (F = 26.55 kN). The deformation data of the single profiles P_i offer the base for the next step of the crack analysis.

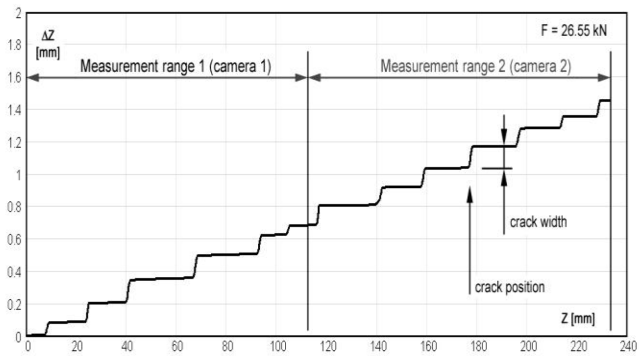

Figure 3. Relative displacements dZ of profile 5 for one load step (26.55 kN)

The next step of the crack analysis detect the position and the width (> $c_{w\,min}$) of the cracks within the profile P_i for every load step. Figure 4 shows a further result, the detected number of cracks during the load test. Figure 5 shows an example for the calculation of the mean crack width during the load test for one profile (P_i = 5) and every load step. The last step combines the data of the single profiles. The results are the means of the crack number and crack width for all profiles and every detected load step.

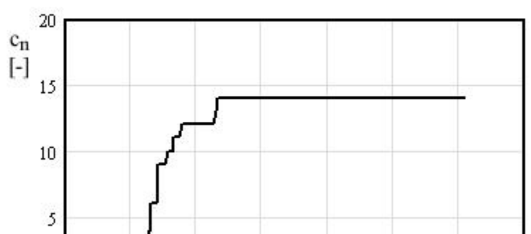

Figure 4. Crack number c_n during the load test

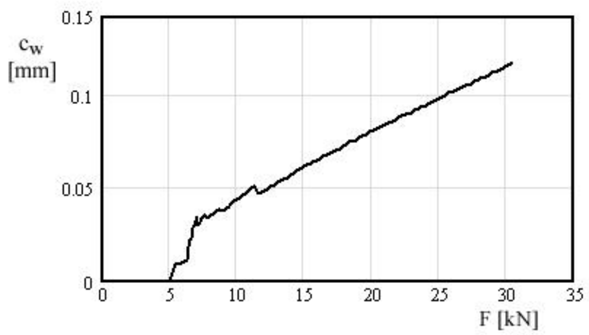

Figure 5. Means of crack width during the load test

3.2 Shear Test (2D/3D)

The second example describes a shear test (Ortlepp et al., 2006). In this case, a textile reinforced bar was applied to an old concrete prism. The intension of this experiment was to analyze the load transmission between the old concrete prism and the textile reinforced concrete bar during the load test. In this context, the crack analysis (crack width and position) was the major task. Figure 6 and 7 show the realized setup. Two digital cameras (Kodak Megaplus 4.2i/10) were used for the photogrammetric measurement. The first measurement area (approx. 130 mm x 100 mm) was detected in 3D. The second and third measurement area (sides of the textile reinforced concrete bar; approx. 130 mm x 10 mm) was detected through two mirrors in 2D. In figure 8 you can see (among other things) the two mirrors.

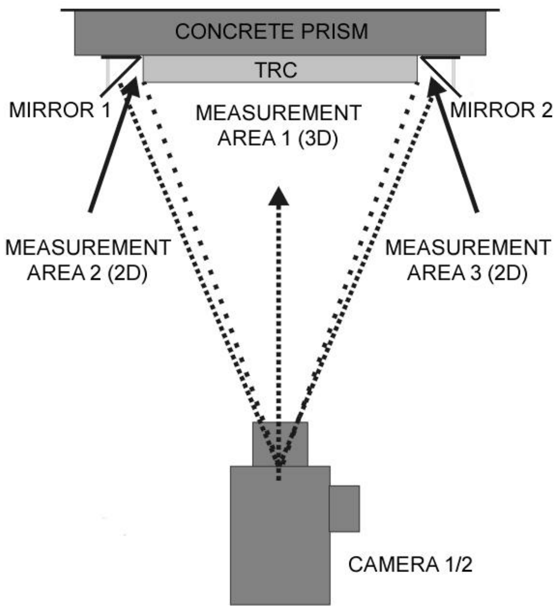

Figure 6. Top view of the test setup of the shear tests (2D/3D)

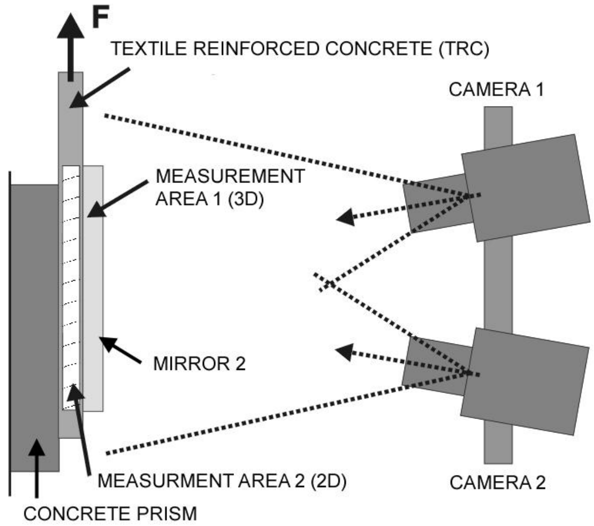

Figure 7. Side view of the test setup of the shear tests (2D/3D)

Figure 8 shows the measurement areas 1-3, including the calculated crack situation for one load step near the breaking point and the used measurement profiles P_i for the further crack analysis. The intensity of the crack color (Figure 8) is an indicator of the crack width. The next steps of the crack analysis are identical with the crack analysis described in section 3.1. For every measurement profile P_i the crack positions and crack widths will be calculated. The results of the crack analysis are the base data for the verification of mechanical models in civil engineering (Ortlepp et al., 2006).

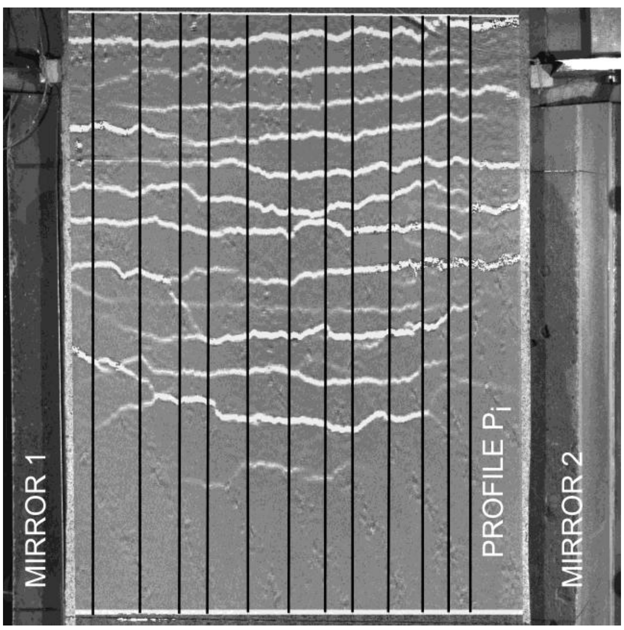

Figure 8. Calculated crack situation for one load step near the breaking point

For a selection of load tests a highspeedcamera FastCam Ultima (Figure 9) was used for the detection of the crash situations. Figure 10 show the crack situation of the measurement area 2 for a period of 2 ms, recorded with 4000 fps. This kind of sequences is very helpful to understand the state of failure.

Figure 9. Highspeedcamera FastCam Ultima

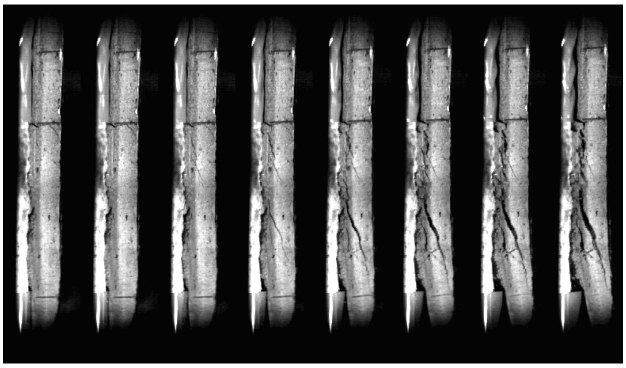

Figure 10. Highspeedcamera-sequence for crack analysis of measurement area 2 (2 ms, 4000 fps)

4. CONCLUSION

The results of the presented experiments have reconfirmed the potential of the digital closed range photogrammetry in civil engineering material testing. The developed modules for crack analysis allow the detection of small cracks (> 5 µm) in a measurement area of approx. 100 mm x 100 mm (2D/3D). Special setups (e. g., 2.5D, mirror photogrammetry ...) allow efficient measurement processes. In case of the presented tension tests of textile reinforced concrete probes, a special 2.5D-setup with a reference system eliminated the influence of the rigid body motions and allows the detection of small cracks (> 5 µm) in a measurement area of approx. 240 mm x 100 mm.
The realized projects confirm that the complexities of some of the measurement processes require optimised algorithms and implementations when it used for mass experiments. The future work will be to continue the development of optimized modules (including algorithms) for the crack analysis (Hampel 2009).

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6. ACKNOWLEDGEMENTS

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