REMOTE SENSING IN LABORATORY DIAGNOSTICS OF REINFORCED CONCRETE ELEMENTS – CURRENT DEVELOPMENT AND VISION FOR THE FUTURE

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Abstract —Continuous emergence of new concrete types and kinds of reinforcement, as well as technological solutions in the field of structural engineering have made great demand for diagnostic tests of reinforced concrete elements. New challenges and problems facing people require new more efficient tools for laboratory diagnostics than those commonly used. Remote sensing may be the answer to this demand. In this paper the author describes how to use terrestrial laser scanning and photogrammetry for laboratory diagnostics of reinforced concrete elements and also presented a vision of how diagnostics of reinforced concrete elements may look like in the future. Suitability analysis of Terrestrial Laser Scanning and photogrammetry for the diagnostics of reinforced concrete elements was carried out as a part of research conducted at Gdańsk University of Technology.

Index Terms — Beam, Cracks, Deformation Measurement, Photogrammetry, Reinforced Concrete, Terrestrial Laser Scanning

I. INTRODUCTION

Reinforced Concrete in its basic form was invented in late XIX century and by that time whole new science was developed. Thousands of scientist all around the world till present day study reinforced concrete as a material as well as reinforced concrete structural elements behavior. Many of research on reinforced concrete elements are conducting in laboratories. Currently the most popular are mechanical methods which some of them being invited in late 60's. World going by and nowadays challenges requires more sophisticated tools. More accurate measurement data translates into better results, which ultimately provides to new scientific discoveries. What is more important not only data accuracy is the issue. Newest tools enable scientist to look at the diagnostic tests in whole new way, which will be described later in this article.

II. CONVENTIONAL APPROACH TO DIAGNOSTICS OF REINFORCED CONCRETE ELEMENTS

Conventional approach to diagnostics of reinforced concrete elements in the laboratory condition based on so called mechanical methods, number of parameters might be specified, such as strain, displacement, force (load), crack opening displacement. In order to measure strain whole range of strain gauges might be used. Resistance strain gauges are based on the relationship between electrical resistance and distortion increase. The advantages of the strain gauge resistance are their ease of use, capacity to maintain continuous measurement and cost efficiency. Downsides of use strain gauges electrical resistivity are sensitive to moisture and susceptibility to mechanical damage of the sensors. For years a device called extensometer has been used as mechanical strain

gauge.

Drawbacks of this method are the lack of capacity to maintain continuous measurement, low accuracy and poor precision.The advantages are following, ease of use and insensitivity to moisture.String strain gauges, use the relationship between the change in frequency of the string vibration and deformation increase. This method is easy to use and provide continuous measurement, main downside is the cost of the sensors.Vertical displacement is examine by means of two devices, clock deflectometer gauge or inductive displacement transducer.During the overloading test of reinforced concrete element, at a certain stage, cracks might occur on element.Crack measurement might be conducted by use of microscope, Brinell magnifying glass or adequately prepared templates. [1]

II. TERRESTRIAL LASER SCANNING

Measurement which based on data from Terrestrial Laser Scanning, involves emitted by the device a coherent light beam that is reflected from the object and returns to the device. The information is collected during the course of the laser beam at a distance from the device to the test object, which allows user to specify the distance, vertical and horizontal angles of incidence of the element. Then the spatial coordinates are calculated, point clouds within seconds is recorded up to 1'000'000 points (scanner Leica ScanStation P30 & P40).A point cloud is a mapping space using a large number of closely spaced points. From the measurements carried out in the laboratory a spatial model might be built. Concrete deformation might be tracked by leaps and bounds in a function of time.

Research on the use of Terrestrial Laser Scanning for laboratory tests of concrete structural elements has been conducted at Gdańsk University of Technology. In this study, several methods which are intended to obtain diagnostic information has been developed.

A. Spheres Translation Method

Data from Terrestrial Laser Scanning might be used to study deformation of reinforced concrete elements in the laboratory condition. Spheres Translation Method consists in conversion of a virtual representation of physical markers which are applied to surfaces, or are a part of the surface, to the virtual mesh elements in a form of spheres.This involves selecting a characteristic point, e.g. flat discs applied regular to the surface of reinforced concrete element (Fig. 1). During post processing part of point cloud which is representing characteristic objects in a model space coordination system will be transformed into spheres composed of a small triangular objects called vertices (singular: vertex). Virtual spheres should be transferred consistently intosubsequent model spaces of further measurements, with the equivalent coordination system. It should be noted that, due to the fact that the position of the scanner in relation to the object is immutable, each model space coordination system will be identical. Through the monitoring spheres position in three-dimensional spaceuser will be able to reconstruct the course of spatial deformation of the scanned concrete object. An analysis was made aimed at determining whether the Spheres Translation Method used with Terrestrial Laser Scanning data, might be considered as a correct and effective method, as part of the research conducted at Gdańsk University of Technology. [2]

Figure 1- Visualisation of Spheres Translation Method

B. Method of Selective Fading

During laboratory tests, concrete element and a scanner remains unchanged in relation to each other, therefore data will be placed in a single coordinate system and then superposed. The individual measurements might be extinguish, through examination in order to recreate the flow of the trial.All measurements might be superimposed and form deformation envelopes, which can be measured and analyzed by using default software measuring tools.Deformation envelopes can be exported to casualFinite Element Method software and apply on analyzed Finite Element Method model (Fig. 2).This feature will allow potential user to check experimental results with analytical predictions in the operative, easy-to-use environment.[2,7]

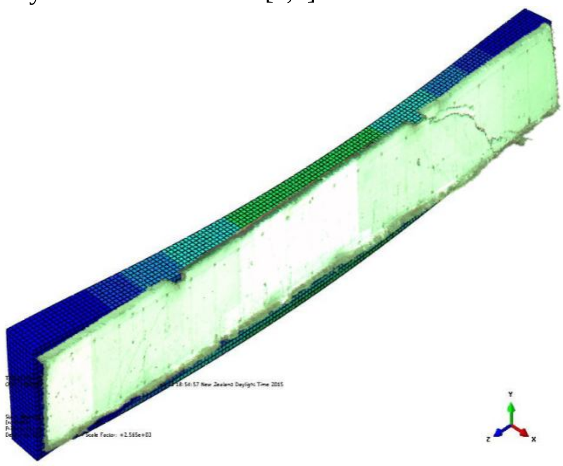


Figure 2- Selective fading method deformation envelope imposed on FEM model of the beam

C. Color Histogram Analysis

Analysis of color histograms specifying how much color there is in a given model can allow to determine crack occurrence. Properly post processed model in a dedicated software might be used to obtain the color histogram. During laboratory test, along with the enlargement of cracks, which are distinguished by the color darker than engobed beam surface, presence of darker colors in histogram will rise, which clearly indicates, assuming no external interference, the appearance of cracks.In order to developed proper method to obtain useful information form the histograms, analysis of point clouds of scanned beam was performed, as part of the research conducted on Gdańsk University of Technology.

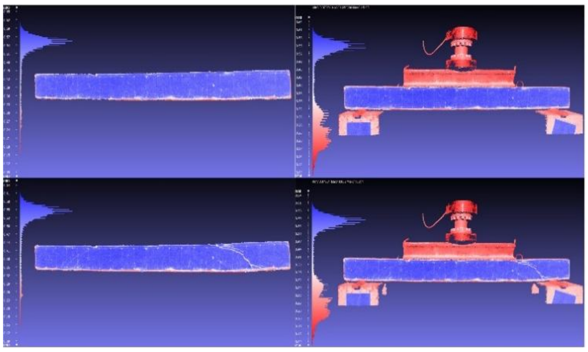


Figure 3- Color Histogram Analysis in open source softwareMeshLAB.

Due to receive meaningful results beam model must be post processed to remove any unnecessary components, interference, and contains only those parts of the model which are significant for the analysis. Every color in the model were brought to the 3 main colors in the following order: red, white, blue.This procedure was aimed at obtaining situation in which any change on the surface of the beam will result in an increase of white color.Subsequently with the cracks enlargement, white color will go to the red color.Comparative analysis of the intensity charts has been processed within use of raster graphics software. Imposed on themselves histograms of reinforced concrete beam measurements before and after the failure.In Figure 3, the main failure crack fills up, first with the white color and then goes into the red spectrum. This jump at the transition from the white color spectrum into the red, might be seen through comparing of the histograms. [7]

IV. PHOTOGRAMMETRY

Photogrammetry is the field of science and technology dealing with the reproduction of shapes, sizes and relative positions of objects in space, based on photogrammetric images. The ordinary application of photogrammetry is to create accurate maps, measuring large areas and distances. It is also one of the methods of determining the height of objects. As a laboratory diagnostic tool, photogrammetry might be used to gathered accurate position of the points on the element and to reproduce progress of deformation. Motion pathways of marked reference points on the object in move also might be recorded and measured. Currently, photogrammetry and image processing allows to use high-speed cameras, synchronous photos, video streaming. Moreover it is possible to tracking objects on the surface of 2D and 3D space. Spatial information about the model can be freely processed using computer vision algorithms, including open source algorithms like OpenCV.

A. Synchro-Photogrammetry by use of synchronous images

Through use of stereo pair of synchronous images and proper post processing it is possible tomeasure of various diagnostic data, including displacements, and strain on the concrete surface. Images from synchronized cameras are the photographs of the same element at the same time from two different spots placed in a short distance to each other.The use of synchronous images and photogrammetry in diagnostics of reinforced concrete beams was carried out as part of research at Gdańsk University of Technology. Photos were carried out in the course of overloading of concrete element during research, load was applied in increments.

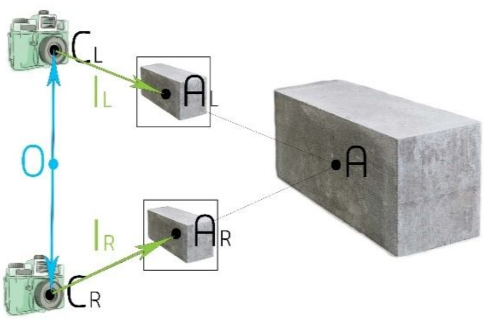
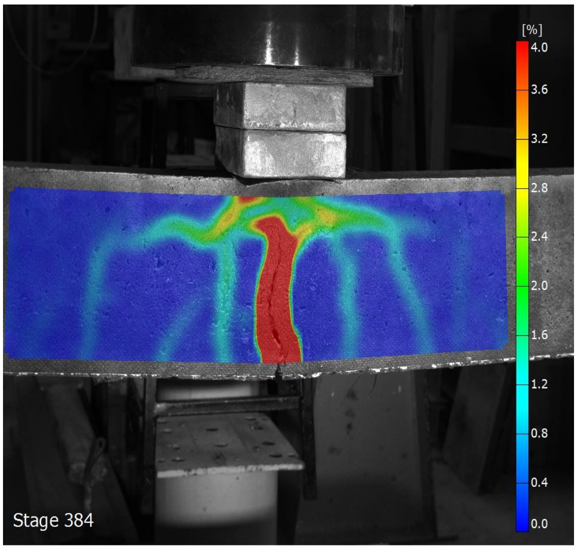


Figure 4 - Photogrammetry test set-up

To carry out photogrammetric measurement and build stereoscopic model is essential to identify point on the object (A in Fig. 4). Selected point on the surface of the concrete shall be represented by two pointsin both stereo pairof synchronous images(A_L and A_R in Fig. 4). Due to generate normalized vectors (I_L and I_R in Fig. 4) camera projections centers(C_L and C_R in Fig. 4) and the point representation (A_L and A_R in Fig. 4) must be merged and update with camera matrix. Fundamental assumption is that two normalized vectors and offset in a form of a vector between cameras centers (O in Fig. 4) are coplanar.

B. Optical 3D Deformation Analysis in Aramis System

ARAMIS system is a remote sensing measuring system providing accurate data for static or dynamically loaded laboratory test objects.By using the Aramis System following items might be tested:surface strain values (major and minor strain, thickness reduction), strain rates, 3D surface coordinates, displacements and velocities.



POLITECHNIKA GDAŃSKA ARAMIS LENSO

Figure 5 - Failure crack during reinforced beam testing.

Aramis system can be used for measurements of cracks in the reinforced concrete elements with an accuracy of ≥ 0.05 mm [4]. However, it may become that micro-cracks may be predicted based on the deformation pattern in the element.Concrete surface has to be prepared in proper way, at first it has to be engobed and then spray over with black ink.The resulting surface is characterized by a dense distribution of black dots on a white surface. The analyzed area will be divided into so-called facets.Error of assessing the change in the distance between the facets is 0.3% with uncertainty estimate of a 0.04 pixel, it has been recommended to take the size of facets 15x15 pixels with the distance between them of 13 pixels.Importance of this error is significantif user want to accurately record the elastic deformation of the reinforced concrete element.

However, if the main goal is to measure larger deformation, this distance might be regarded as satisfactory. Size of the facets also affects the calculation speed, which decreases with the growth of the measurement area.If the measurement requires a large amount of registered images and a large measurement area, which filling almost the whole cameras field of view, use of larger facets should be considered due to reduce the computation time.

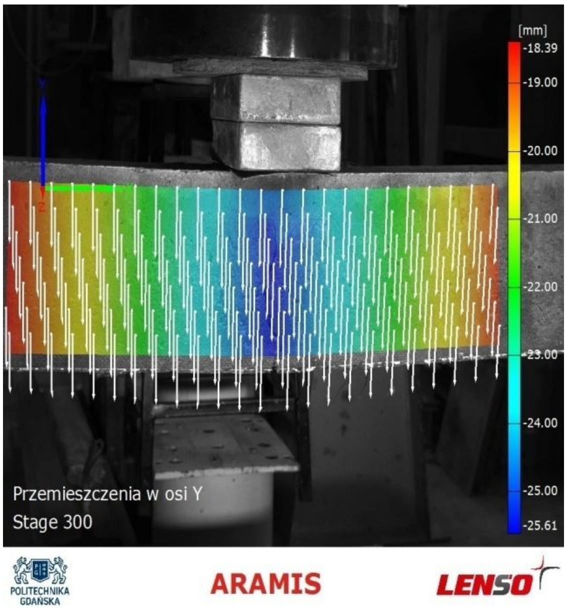


Figure 6 – Deformation in axis X

V. VISION FOR THE FUTURE

A. Autonomous Drone with tactile microfibers optical sensors

Sense of touch is commonly found in nature. In the future labs, autonomous drones will be scanning surface of the concrete by tactile microfibers sensors. Planar sensors will be covered with microfibers which will penetrate every crack during the measurement and send that data into the computer. On the base of this data computer will reconstruct the surface of the reinforced concrete elementsand transmits to user useful information about e.g. opening of micro cracks, texture of surface.

B. TLS and photogrammetry hybrid system

Hybrid connection of Terrestrial Laser Scanning and photogrammetry has been tested during research conducted on Gdańsk University of Technology. [7]Both technologies work together perfectly and complement each other. Terrestrial laser scanning provide accurate data about exact element position, shape and major cracks distribution, whereas data from synchronous photogrammetry delivers detailed information about distribution of cracks on concrete element surface and validate data from Terrestrial Laser Scanning.Further studieswhich will be conducted at Gdańsk University of Technology will focus ondevelopment of a method to correlating data from two sources more easily.

C. 3D real-time imagingby Nano object tracking

It is possible that in the future Nano objects will be mixed with aggregate and concreted in reinforce concrete element. Nano objects will be transmitting information about their position and deformation of its surface directly to the computer. On the base ofdata, from this tiny devices, algorithm will create an internal 3D image of reinforced concrete beam during research. This device will offer anamazing opportunity to insight into process of internal conversion of concrete body in real-time.

CONCLUSION

Remote sensing takes on new meaning in the areas in which has not been used. This technology will slowly displace existing measurement methods based on the use of a wide range of strain gauge and laborious compiling such obtained data. Terrestrial Laser Scanning and photogrammetry until recently were the domain of geodesy and navigation, using them in such areas like structural engineering has brought a whole new quality. The use of Terrestrial Laser Scanning and photogrammetry in the diagnosis of concrete elements have been studied at Gdańsk University of Technology, within which were developed three practical measurement methods using data from Terrestrial Laser Scanning (Spheres Translation Method, Method of Selective Fading, Color Histogram Analysis) and proposed to use a hybrid of both these techniques. The biggest advantage of using remote sensing to laboratory diagnostics of reinforced concrete elements is comprehensive of gathered data, allowing to examine even the smallest deformations in the course of studies. The author will continue research on the use of remote sensing in laboratory diagnostics of reinforced concrete elements.

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