Sensors & Transducers, Vol. 200, Issue 5, May 2016, pp. 66-70

Sensors & Transducers
© 2016 by IFSA Publishing, S. L.
http://www.sensorsportal.com

Research on Mechanical Properties of Concrete Constructs Based on Terrestrial Laser Scanning Measurement

[1, 2] Hao Yang and [2 *] Xiangyang Xu

[1] Jiangsu University of Science and Technology, Zhenjiang City, Jiangsu Province, P. R. China
[2] Geodetic Institute, Faculty of Civil Engineering and Geodetic Science, Leibniz University Hanover, Nienburger Street 1. D-30167, B260, Hanover, Germany
[*] E-mail: xu@gih.uni-hannover.de

Received: 29 April 2016 /Accepted: 27 May 2016 /Published: 31 May 2016

Abstract: Terrestrial laser scanning (TLS) technology is broadly accepted as a structural health monitoring device for reinforced concrete (RC) composite structures. Both experiments and numerical analysis are considered. In this submit, measurements were conducted for the composite concrete beams. The emphasis in numerical simulation is given on finite element methods (FEM) which is corrected by the response surface methodology (RSM). Aspects considered are effects of material parameters and variation in geometry. This paper describes our recent progress on FEM modeling of damages in concrete composite structures based on the TLS measurement. We also focus on the research about mechanical properties of concrete constructs here. *Copyright © 2016 IFSA Publishing, S. L.*

Keywords: Reinforced concrete, TLS, FEM, Composite structures.

1. Introduction

Terrestrial laser scanning (TLS) technology is broadly accepted as a structural health monitoring device for reinforced concrete (RC) composite structures. Both experiments and numerical analysis are considered. In this submit, measurements were conducted for the composite concrete beams. The emphasis in numerical simulation is given on the finite element methods (FEM) which is corrected by the response surface methodology (RSM). Aspects considered are effects of material parameters and variation in geometry. This paper describes our recent progress on FEM modeling of damages in concrete composite structures, based on the TLS measurement and RSM optimization.

1.1. Motivation

Terrestrial laser scanning technology (TLS) has become one of the most important technologies for acquisition of three-dimensional (3D) information of objects. TLS, which is a promising method in health monitoring of structures, can provide highly accurate, non-contact measurements of the whole structure. Its benefit lies mainly on a permanent availability of measurement data, and a possible combination with the finite element method (FEM) model. Because the TLS measurement is area-oriented rather than point-oriented, it has significant advantage when compared with traditional measurements in structural analyses.

Finite element method (FEM) is an efficient, commonly used numerical method. For most complex engineering structures, it is quite difficult to obtain analytical solutions for structure problems, due to the complexity of geometry, load, constrains and so on. Instead, with the development of computer science, the approximate numerical solutions which satisfy engineering requirements are more achievable. Currently, FEM is an important method and tool in structure analysis.

In this thesis, health monitoring of structures based on TLS is investigated and a FEM model is constructed. The goal focuses on the benefits of 3D TLS in the generation and calibration of FEM model, in order to build an efficient and intelligent model which can be widely used for assessment of objects. As an example, we constructed an acceptable model which is able to be applied in the assessment of concrete structures.

1.2. Proposal

The general motivation is to study the benefit of TLS in the field of FEM calibration, mostly from two aspects: the first is deformation measurement and the second is crack detection. The benefit of TLS lies mainly in the possibility of a surface-based validation of results predicted by the FEM model. Within this study TLS should be used in order to determine the surface based geometric behavior of the structures within load experiments. Dominant innovation is to find different reliable criteria based on TLS measurement in order to correct and update FEM model. The criteria are, for example, the maximum of displacement, the volume of the deformation and cracks on the surface. Here, both of displacement and volume involve surface approximation which makes full use of the 3D coordinates of the point clouds from TLS. Crack computation is mainly based on the intensity information of the TLS measurement results.

With the beneficial use of TLS, the FEM model of the structure is required to be calibrated for higher reliability, so as to obtain accurate predictions of structures. In this case, response surface methodology (RSM) is adopted to correct and update the FEM model. The displacement- and volume-based RSM updating are applied and the significance of RSM models are confirmed by the determination coefficient R^2. MATLAB programs for polynomial approximation and concrete cracks detection from the TLS point clouds data are developed. The general processes of FEM calibration based on TLS measurement is shown in Fig. 1.

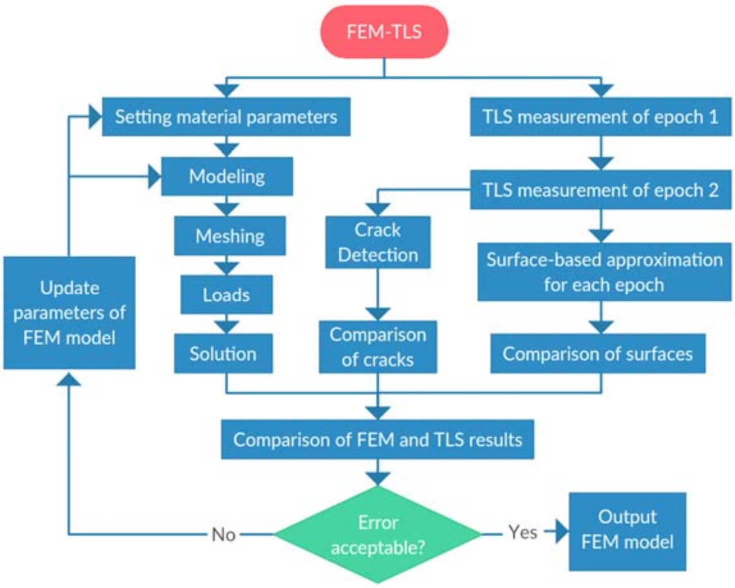


Fig. 1. The processes of FEM calibration based on TLS measurement.

In Fig. 1, the left side is FEM model analysis which includes parameters setting, modeling, meshing, load and solution. The right side is the TLS measurement and data processing. After TLS measurement of epoch data, the TLS data are processed in two ways: deformation and cracks. The deformation is calculated by surface-based approximation and surface difference analysis. The cracks are calculated by crack detection calculation and comparison of cracks which will result in crack changes. The following step is a comparison of TLS results and FEM model simulation. If the two are not agreeable, FEM model will be updated, till the error between TLS results and FEM model is acceptable. At last, an accurate and reliable FEM model based on TLS measurement is obtained.

There are four sections in this thesis. Section 1 is the introduction of this thesis which contains my motivation and proposal. Section 2 is about FEM, where there are the following parts: a summary of FEM development, general description of dynamic and static-based FEM calibration, different methods of

FEM calibration, and at last, a general summary of FEM simulation of deformation and cracks. The general description of dynamic and static-based FEM calibration is written from the view of experiment, while the introduction of different methods of FEM calibration focuses on several calibration calculation methodology, including the highlighted RSM method. Section 3 presents TLS measurement, surface approximation and crack detection. Section 4 is the statement of innovations with a connection to the general papers from my thesis.

2. Finite Element Model

Finite Element Method (FEM) is widely used to solve structural problems in engineering analysis and design. It utilizes mathematical models to settle physical problems and get the finite element solution [1]. The main processes of FEM analysis are: graphical pre-processing, finite element kernel calculation and graphical post-processing [2].

2.1. Development of FEM

The origins of FEM came from the matrix method in structural analysis in 1910; from 1940, Hrennikoff used grid elements in calculation [3] and Courant mentioned piecewise continuous functions in triangle region and the principle of minimum potential energy in St. Venant torsion problem [4]; and later in 1956, Turner et al. found the direct stiffness method [5]; from about 1960 till now, many researchers study variational formulation, such as Zienkiewicz and Taylor in 1967 [6]. FEM has gained rapid development due to the practical application of computer science since about 1970. As a numerical analysis method for structures, FEM has been widely used in civil engineering, aeronautics and astronautics, mechanical engineering, vehicle engineering, medicine, and so on.

2.2. FEM Model of Reinforced Concrete

Plain concrete, composed of aggregates, cement and admixtures, is widely used in civil engineering. To improve its mechanical properties, reinforcements like rebars are usually added in and make up a so-called composite material-reinforced concrete. In some cases, the rebars are stretched or prepressed which produce a pre-compression on the concrete and delay the cracks development. This is said to be a prestressed concrete beam. The concrete material discussed in the thesis is unprestressed reinforced concrete. Concrete has complicated behaviors in uniaxial, biaxial and three axial loads. Here, the uniaxial situation is discussed to have an overview of the mechanics of concrete.

2.3. Properties of Reinforced Concrete

A plain concrete beam (Fig. 2b) fails very suddenly and completely when the first crack forms [7]. However, in a reinforced concrete beam (Fig. 2c), the rebars offer a moment equilibrium to the tension and improve the mechanical properties of the concrete [7].

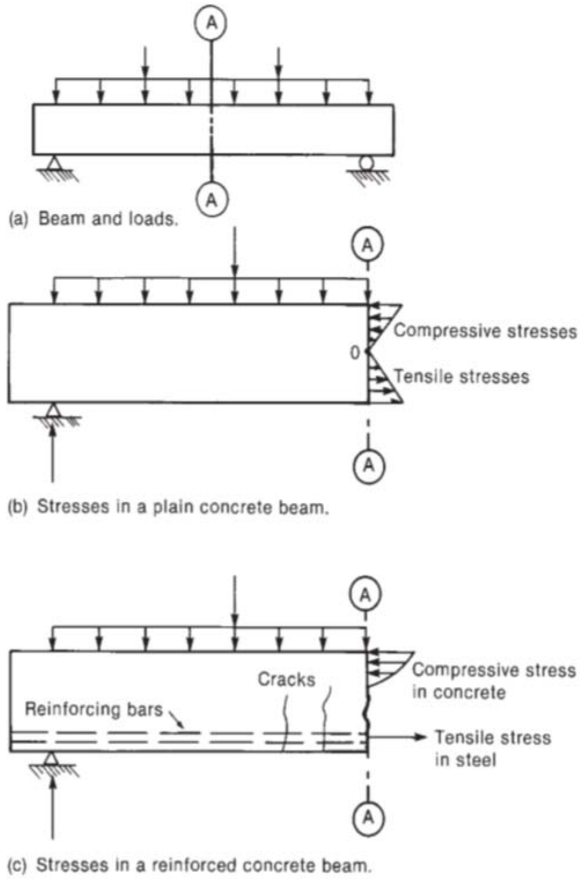
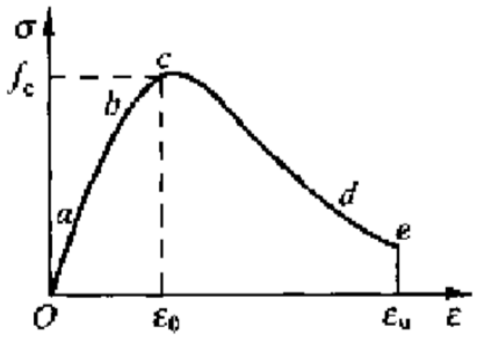


Fig. 2. Plain and reinforced concrete beams [7].

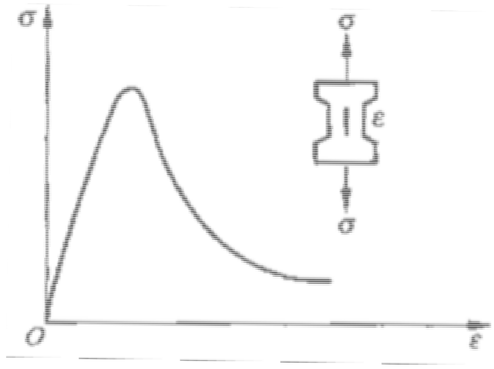
2.4. Mechanical Properties of Concrete

Fig. 3-a shows stress-strain curve of concrete in uniaxial compression. It goes through a nearly linear section *oa* and an nonlinear section *ab*, and then rises from critical stress point b till the peak stress point *c*. After that, the stress will decrease until the strain reaches the ultimate strain value. The stress at point a is approximate (0.3~0.4) f_c, and b is (0.8~0.9) f_c. A stress-strain curve of concrete from uniaxial tension was obtained by Peterson from Lund University in Sweden through an experiment in 1981 (see Fig. 3-b) [8], where we can see that the rising section is approximately linear but declining section is steep.

Rebars usually adopt materials like Q235, 20MnSi, 25MnSi, 40Si2MnV etc. Qualification of rebars means enough strength and a certain level of plastic deformation ability, fire resistance, adhesive force [9].



(a)



(b)

Fig. 3. The stress-strain curve of concrete in uniaxial compression and tension [8].

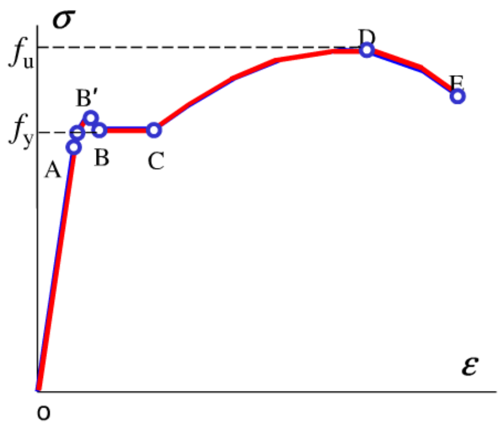


Fig. 4. The strain-stress curve of rebars.

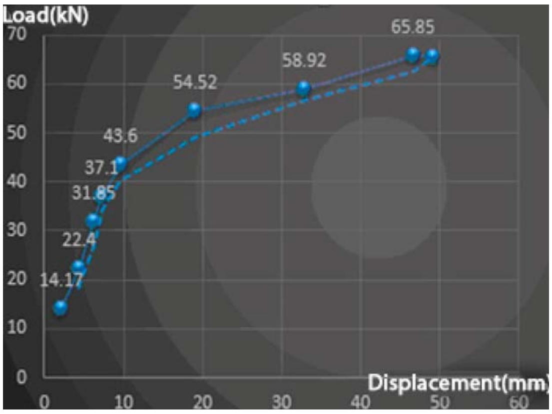


Fig 5. The load-displacement curve [10].

The mechanical behavior of rebar is characterized by uniaxial tension stress. There are four stages in the failure process of typical rebars. The first is the elastic stage (section OA) with a linear relation between strain and stress; the second is the yield stage (section AC), where stress is relatively stable but the strain increases greatly and plastic deformation occurs; the third is the strengthening stage (section CD) where the stress increases and the resistance ability to stretching raises; the fourth is the necking stage (section DE), where local cross section suddenly narrows, and the stress decreases till fracture at point *E*. The parameters in Fig. 4 are the lower yield strength, f_y and the peak strength, f_u.

3. Experiment

In Fig. 5, the y axis is the force with units of kN and the x axis is the displacement with units of mm. We can see an obvious inflection point at the fifth epoch with force 43.6 kN which should be related to the yield strength [10]. After the data has been analyzed and the FEM model is simulated, we compare this FEM model with experimental data epoch 1 which not only presents the relationship between displacement and force of single point, but also compares the point distribution on the surface.

4. Result

Comparing the strain-stress curve of rebars (Fig. 4) with the load-displacement curve (Fig. 5), we can observe that linear section *AB* and *CD* are agreed with the each other. But the section *BC* is different with the experiment data. It means that the reinforced concrete composite constructs have more stable and dependably properties.

Acknowledgments

The authors of this paper are supported by Deutsche Forschungsgemeinschaft and Open Access Publishing Fund of Leibniz Universität Hannover. The authors would like to acknowledge the support of all the colleagues in Geodetic Institute of Leibniz University Hanover for their valid information.

Reference

[1]. K. J. Bathe, Finite element procedures, *Prentice Hall*, Englewood Cliffs, N. J., USA, 1996.

[2]. U. Nackenhorst, Handbook: Numerische Mechanik WS 14/15, *Gottfried Wilhelm Leibniz Universität*, Hannover, 2014.

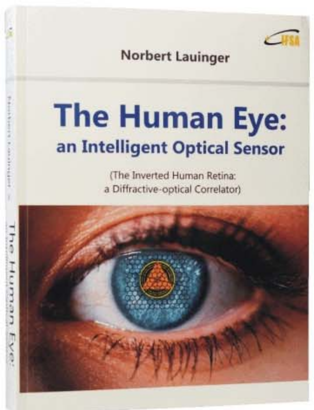
[3]. A. Hrennikoff, Solution of problems of elasticity by the framework method, *Journal of Applied Mechanics*, 8, 4, 1941, pp. 169–175.
[4]. R. Courant, Variational methods for the solution of problems of equilibrium and vibrations, *Bulletin of the American Mathematical Society*, 49, 1943, pp. 1–23.
[5]. M. J. Turner, R. W. Clough, H. C. Martin and L. J. Topp, Stiffness and deflection analysis of complex structures, *Journal of Aeronautics Sciences*, 23, 9, 1956, pp. 805–823.
[6]. O. C. Zienkiewicz and R. L. Taylor, The finite element method, *Elsevier Butterworth-Heinemann*, Oxford, UK, 54–97, 2005.
[7]. J. K. Wight and J. G. Macgregor, Reinforced concrete: mechanics and design, *Pearson Education, Inc.*, New Jersey, America, 2011.
[8]. V. Cervenka, J. Cervenka and R. Pukl, ATENA-A tool for engineering analysis of fracture in concrete, *Sadhana*, Vol. 27, Issue 4, 2002, pp. 485-492.
[9]. Standard for steel material in reinforced concrete, GB1499, 2-2007, China, 2007.
[10]. H. Yang, X. Xu, I. Neumann, The Benefit of 3D Laser Scanning Technology in the Generation and Calibration of FEM Models for Health Assessment of Concrete Structures, *Sensors*, 14, 2014, pp. 21889–21904.

2016 Copyright ©, International Frequency Sensor Association (IFSA) Publishing, S. L. All rights reserved.
(http://www.sensorsportal.com)

Norbert Lauinger

The Human Eye: an Intelligent Optical Sensor

(The Inverted Human Retina: a Diffractive-optical Correlator)

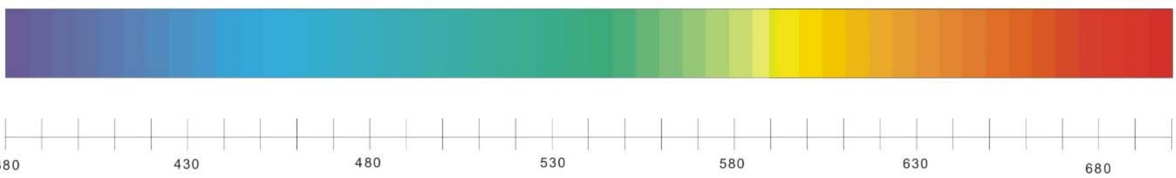


The Human Eye: an intelligent optical sensor (The inverted retina: a diffractive - optical correlator) shows that the human eye from the prenatal structuring of the inverted retina hardware on up to the design of the central cortical visual pathway is not only different from but also radically more intelligent than a camera.

Many paradoxes in color vision (RGB peak positioning in the visible spectrum, overlapping of the RGB channels, relating local color to the whole scene, paradoxically colored shadows, Purkinje phenomenon etc.) are becoming intelligent solutions.

A fascinating book for all those wondering that the brightness of a scene is not cut in half and that the visible world doesn't collapse into a flat 2D-image when closing one eye. It should be a great of interest for students, scientists and engineers in eye-, vision- and brain-research, neuroscience, psychophysics, ophthalmology, psychology, optical sensor and diffractive optical engineering. Practical applications are the search for a retinal implant of the next generation and a helpful strategy against myopia in early childhood.

Hardcover: ISBN 978-84-617-2934-0
e-Book: ISBN 978-84-617-2955-5



Order: http://www.sensorsportal.com/HTML/BOOKSTORE/Human_Eye.htm