Analysis of Inhomogeneous Structural Monitoring Data

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Dissertation

Graz University of Technology

Graz, January 2007

Series Editor

Fritz K. Brunner

Engineering Geodesy and Measurement Systems
Graz University of Technology
Steyrergasse 30, A-8010 Graz, Austria
http://www.igms.tugraz.at

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Shaker Verlag
Aachen 2007

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Graz, Techn. Univ., Diss., 2006

The dissertation was submitted to the Faculty of Civil Engineering Sciences at the Graz University of Technology for achieving the academic degree of Doctorate of Technical Sciences.

Examination Committee:

Examiner: Univ.-Prof. Dr. Fritz K. Brunner
Second Examiner: Univ.-Prof. Dr.-Ing. Willfried Schwarz

Day of oral examination: November 21, 2006

Printed in Germany.

ISBN 978-3-8322-5953-2
ISSN 1864-2462

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen
Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9
Internet: www.shaker.de • e-mail: info@shaker.de

Abstract

Today, deformation measurements are not the sole competence of surveyors anymore as geodetic sensors (tacheometers, GPS, etc.) are commonly used simultaneously with sensors of other disciplines. Although, the combined analysis appears straight forward at the first glance, problems arise when connection measurements between spatially distributed sensors are missing. Furthermore, in practice the measurements of different sensor types are often carried out by different groups and are rarely made simultaneously. The general situation is therefore given by spatially distributed measurements of different types and scattered in time.

In this thesis an Integrated Analysis Method (IAM) is proposed which allows the use of spatially distributed, hybrid measurements taken at different times in combination with a Finite Element Model (FEM). With the proposed method it is possible to separate deformations caused by regular changes (e.g. temperature changes) from deformations induced by damage (e.g. cracks, material deterioration). The generic method can be applied to inhomogeneous monitoring data of any structure as long as a physical model can be established. The method consists of a measurement part and of a system part. The system part is derived from the physical model. Both parts are connected by the condition that measured and predicted deformations have to be the same. The condition equations are introduced as observations with very high weight. The physical parameters are then estimated in a least squares estimation.

The IAM is applied to the monitoring data of a monolithic bridge which is characterized by the absence of bridge bearings and expansion joints. For the measurement of strain in the concrete deck eight fiber optical deformation sensors (about 5m long) were embedded. The sensors that were used are part of the SOFO system of SMARTEC which claims a precision of 2µm for the measurement of length variations. The performance of the measurement system with respect to precision, temperature sensitivity and long-term stability was investigated in detail. The specified precision could be fully confirmed in laboratory experiments and for sensors embedded in concrete. A small temperature dependence of the reading unit was detected which is negligible in most applications but can be eliminated by applying a linear correction function. Concerning the sensor's durability it was shown that the driving power of the light source of the instrument is an indicator of the sensor's health status.

Twelve temperature sensors were also embedded in the concrete deck of the monolithic bridge in order to investigate the correlation of the deformations with temperature changes. In addition to the internal deformations, height changes of selected points were determined by repeated precise levelling and the positional variations of the entire bridge were measured by repeated traverses. Furthermore, the shape changes of two bridge piles were observed using borehole inclinometers.

The deformations of the bridge due to temperature changes were predicted using a specially developed FEM. The measured deformations were used to gradually improve the physical model of the monolithic bridge. With the calibrated FEM and the proposed IAM it was possible to separate deformations induced by temperature changes from deformations caused by concrete shrinkage and settlements.

Zusammenfassung

In der Bauwerksüberwachung hat der Geodät vielfach die Monopolstellung verloren. Heutzutage werden häufig geodätische Sensoren (Tacheometer, GPS, ...) gemeinsam mit Sensoren anderer Disziplinen eingesetzt. Obwohl die gemeinsame Auswertung der hybriden Messdaten auf den ersten Blick einfach erscheint, treten Probleme auf, wenn Verbindungsmessungen zwischen räumlich verteilten Sensoren fehlen. In der Praxis werden die Messungen der unterschiedlichen Sensortypen oft von verschiedenen Messtrupps durchgeführt und finden selten gleichzeitig statt. Meistens liegen daher räumlich verteilte, hybride Messdaten vor, die zu unterschiedlichen Zeitpunkten gemessen worden sind.

In dieser Arbeit wird eine Integrierte Auswertemethode (IAM) vorgestellt mit der solche Daten in Kombination mit einem Finite Element Modell (FEM) ausgewertet werden können. Mit der vorgestellten Methode ist es möglich reguläre Deformationen (z.B. aufgrund von Temperaturänderungen) von Deformationen verursacht durch

Bauwerksschäden (z.B. Risse, Materialveränderungen) zu trennen. Die Methode ist generisch und kann auf inhomogene Überwachungsdaten eines beliebigen Bauwerks angewendet werden, wenn ein physikalisches Model der Struktur vorhanden ist. Die Methode unterscheidet zwischen einem Messteil und einem Systemteil. Der Systemteil wird aus dem physikalischen Modell abgeleitet. Die Bedingung, dass die gemessenen und berechneten Deformationen identisch sein müssen, schafft die Verbindung zwischen dem Mess- und dem Systemteil. Die Bedingungsgleichungen werden als Beobachtungen mit sehr hohem Gewicht eingeführt. Die Parameter des physikalischen Modells werden dann mittels Parameterschätzung nach kleinsten Quadraten bestimmt.

Die IAM wird auf die Deformationsmessungen einer monolithischen Brücke ohne Lager und Dehnungsfugen angewendet. Für die Messung von Dehnungen im Betondeck wurden acht faseroptische Sensoren im Brückendeck eingebettet. Die verwendeten Sensoren sind Teil des SOFO Messsystems von SMARTEC mit welchem Längenänderungen mit einer Präzision von 2µm bestimmt werden können. Das SOFO Messsystem wurde in Bezug auf erreichbare Präzision, Temperaturabhängigkeit und Langzeitstabilität im Detail untersucht. Die vom Hersteller spezifizierte Präzision konnte bestätigt werden. Für die Auswerteeinheit des Messsystems wurde eine geringfügige Temperaturabhängigkeit nachgewiesen, welche durch eine lineare Korrekturfunktion eliminiert werden kann. Für die meisten Anwendungen dürfte dieser Einfluss aber vernachlässigbar sein. Bezüglich der Haltbarkeit der Sensoren wurde gezeigt, dass die Stromstärke mit der die Lichtquelle des Messsystems betrieben wird, als Indikator für den Sensorzustand verwendet werden kann.

Um den Zusammenhang zwischen Deformationen und Temperaturänderungen bestimmen zu können, wurden zwölf Temperatursensoren im Brückendeck einbetoniert. Zusätzlich zu den internen Deformationen wurden Höhenänderungen von ausgewählten Brückenpunkten durch wiederholte Präzisionsnivellements bestimmt. Weiters wurden die Lageänderungen von einzelnen Punkten durch Polygonzugsmessungen bestimmt. Die Formänderungen von zwei Brückenpfählen konnten durch Inklinometermessungen verfolgt werden.

Die Brückendeformationen aufgrund von Temperaturänderungen wurden mit einem FEM vorhergesagt. Mit den gemessen Deformationen wurde das physikalische Modell der monolithischen Brücke schrittweise verbessert. Mit dem kalibrierten FEM und der vorgestellten IAM war es möglich temperaturinduzierte Deformationen von Deformationen mit anderen Ursachen wie Betonschwinden und Setzungen zu trennen.

Acknowledgements

This work would not have been possible without the support of many people to whom I want to express my gratitude.

First of all, I want to thank my supervisor Prof. Fritz K. Brunner for all his advise and help during the years in which this thesis evolved. He made me responsible for the measurements on a unique structure and the analysis of the data. Originally, the monitoring project was only one of many projects that I worked on at the Institute of Engineering Geodesy and Measurement Systems (EGMS). It was Prof. Fritz Brunner who realized that my mind always went back to the controversial monitoring data. Despite different initial plans the analysis of the monitoring data became my obsession within the last few years and is now the central part of this thesis. He also came up with the idea to introduce a physical model to replace the missing connection measurements and was always supportive when I needed financial support for additional measurements or required equipment for the experiments in the laboratory. I want to thank him especially for giving me the freedom to make all the experiments with the SOFO measurement system.

I want to thank the staff of ZT Eisner, especially DI Herbert Högler who made the design of the monolithic bridge, for the opportunity to carry out measurements on the unique structure. In this context I also have to thank Prof. Lutz Sparowitz who established the connection between the ZT Eisner and EGMS.

I acknowledge the help of Dr. Roman Marte from the civil engineering office Garber – Dalmatiner who provided the inclinometer measurements, thus enabling me to use monitoring data from many different sensor types.

The construction and monitoring of the structure was partly funded by the Austrian Industrial Research Promotion Fund (FFF), which I also want to acknowledge.

A great 'thank you' to all members from EGMS for their support and the joyful working atmosphere. In particular I want to thank Fritz Zobl and Rudolf Lummerstorfer for their support in the field work and Robert Presl for his invaluable help during the experiments in the laboratory. I also want to thank Helmut Woschitz for the discussions on the laboratory climate and on calibration issues in general. I deeply appreciate all the discussions I had with Andreas Wieser on least squares estimation and statistical tests. Crucial support was given by Sandra Schmuck who organized literature from all around the globe.

For me it would not have been possible to establish the detailed physical model of the bridge without the help of Christoph Wiltafsky from whom I learned many secrets of the Finite Element program ABAQUS.

I also want to thank Dr. Daniele Inaudi who developed the SOFO measurement system and answered all my questions about its inner workings, and Prof. Rainer Jäger for providing information on his work on which the Integrated Analysis could be built on.

I want to thank my parents and my brother who never really knew what I was doing but supported me without questioning.

The person I have to thank the most is my wife Susanne. I could have never finished this thesis without her constant support and help. She is the one who had to sacrifice our common time and also spent nights in the laboratory to take readings of analogue translation stages.

Finally I want to thank my two children Jakob and Katharina who were born during the last three years. Jakob became a regular visitor at the university and knows the laboratory now better than most students.

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