ACTIVITY OF THE FIG WORKING GROUP 6.1 ON DEFORMATION MEASUREMENTS – PROGRESS REPORT 2006-2008

Adam CHRZANOWSKI[1] and Cecilia WHITAKER[2]
[1]*Canadian Centre for Geodetic Engineering, University of New Brunswick, Canada*
[2]*Metropolitan Water District of Southern California USA*

Abstract: International symposia organized by FIG Working Group 6.1 provide international forum for the exchange of information on developments of new techniques and methods for monitoring and analysis of structural and ground deformation. International Task Forces are established to solve specific problems that are identified by researchers and users of the new methods and techniques. Currently, the following Task Forces (TF) are active:
TF 6.1.3: Optimal Use of Interferometric Synthetic Aperture Radar (InSAR);
TF 6.1.4: Monitoring and Analysis of Cyclic Deformations and Structural Vibrations;
TF 6.1.5: Remote Engineering Surveys with Terrestrial Laser Scanning techniques;
TF 6.1.6: Geodetic Engineering in Crustal Deformation Studies;
TF 6.1.7: Continuum Mechanics as a Support for deformation Monitoring.
A summary of progress reports submitted by the Task Forces is presented.

1. INTRODUCTION

Activity of FIG Working Group 6.1 (WG 6.1) on Deformation Measurements dates back to 1975 when the first FIG international symposium on deformation measurements was held in Krakow, Poland. Between 1975 and 1986, the WG6.1 was chaired by Dr. A. Platek of Poland. In 1986, Dr. Adam Chrzanowski of Canada, became the new chair and he carries the position till today. In 2001, Cecilia Whitaker of USA became the Vice-chair. She has done an excellent job in organizing the dissemination of information about the activity of the Working Group.

The main goals of WG 6.1 are: creation of an international forum for the dissemination of knowledge on new developments in deformation monitoring and analysis and stimulation of international co-operation in solving specific (*ad hoc*) problems related to deformation monitoring.

The dissemination of knowledge is achieved by organising international symposia and technical sessions at FIG Congresses related to deformation measurements. In total, WG6.1 has organised thirteen international symposia, most of them in Europe, with the 12th symposium held in Baden, Austria, in 2006 and the 13th symposium being held in Lisbon. Only four symposia were held overseas with two symposia held in Canada (1988 and 1993), one in Hong Kong (1996), and one in the USA (2001). Till 1986, the symposia focused mainly on geodetic aspects of deformation monitoring. In1988, at the 5th Symposium in Fredericton, Canada, the work of the WG6.1 was expanded into multidisciplinary approach to deformation monitoring and analysis with an increased participation in the symposia by specialists in other fields of engineering and geoscience.

The solution of the *ad hoc* problems has been handled by special Task Forces. In 1978, an *ad hoc* committee (Task Force 6.1.1), chaired by Adam Chrzanowski, was created to solve problems in geometrical analysis of deformations. Practically, all problems of geometrical analysis of deformation measurements were solved by that committee including the development of the Generalized Method of Geometrical Analysis (Chrzanowski and Chen, 1986; Chrzanowski et al., 1986) and iterative weighted similarity transformation (Chen et al., 1990) of displacements for detecting unstable reference points. The final report (Chrzanowski and Chen, 1986) was presented at the FIG Congress in Toronto, Canada, in 1986. In 1992, an *ad hoc* Committee (Task Force 6.1.2) on Terminology and Classification of Deformation Models was created. The work of the committee was completed in 2001 and the results were published by FIG as a publication No. 25 (Welsch and Heunecke, 2001).

Currently, 5 Task Forces are actively engaged in solving problems related to new technologies and methods of analysis:

TF 6.1.3: Optimal Use of Interferometric Synthetic Aperture Radar (InSAR);
TF 6.1.4: Monitoring and Analysis of Cyclic Deformations and Structural Vibrations;
TF 6.1.5: Remote Engineering Surveys with Terrestrial Laser Scanning Techniques;
TF 6.1.6: Analysis of Crustal Deformation Data;
TF 6.1.7: Continuum Mechanics as a Support for Deformation Monitoring.

Brief reports on the last two years activities of the task forces are presented below.

2. REPORT OF TF 6.1.3 – INTERFEROMETRIC SYNTHETIC APERTURE RADAR

The Task Force was established in 2002. This report has been compiled from information submitted by Dr. Xiaoli, Ding, Chair, TF 6.1.3 (e-mail: lsxlding@polyu.edu.hk)

2.1. Objectives of TF 6.1.3

The main objectives of this Task Force are to understand the performance of the InSAR technology in deformation measurements under different conditions, and to develop methods to enhance the quality of InSAR measurements. More specifically, the Task Force aims to:

1. study the accuracy and reliability of InSAR in measuring ground deformations under various atmospheric, terrain (e.g., topographic and surface types) and imaging (e.g., temporal and spatial baselines, radar wavelengths) conditions;
2. develop new and innovative methods for processing and modelling SAR data to achieve better measurement results especially under difficult conditions;
3. study methods for integrating InSAR and other technologies such as GPS
4. develop new applications of the InSAR technology.

2.2. Activity 2006-2007

2.2.1 Atmospheric Effects on InSAR Measurements

Over the last 3 years, the work of the Task Force concentrated on a better understanding of the properties of the atmospheric effects and to develop methods for mitigating the effects. The TF studied, for example, the magnitudes of the effects in the various parts of the world, the spectra of the atmospheric effects, the isotropic properties and the statistical distributions of the effects. Various methods have been developed for mitigating the atmospheric effects, including the methods that are based on interferogram modeling, and those that are based on external data such as GPS observations, ground meteorological data, and satellite data including those from the MODIS and MERIS. Significant improvements can be made to the quality of InSAR measurements when the methods are applied (Li et al.2006a; Li et al. 2006b; Li et al. 2007)

2.2.2 Development of Interferogram Filters

The accuracy of InSAR measurements is highly dependent on the quality of the interferogram formed based on two or more SAR images. Due to the effects of various decorrelation factors, such as geometrical and temporal de-correlations, Doppler centroid variations, and data processing problems, the phases in a SAR interferogram are often noisy. In addition to introducing noise into the DEM and deformation measurements, phase noise can also cause pseudo phase residues that hinder the process of phase unwrapping.

Work has been carried out to develop new and more effective interferogram filters to reduce the noise in interferograms. A new least squares-based filter has been proposed that is shown to be superior to the existing interferogram filters. Modifications to the Goldstein filter have also been proposed where the filter parameter can be better determined.

2.2.3 Other Developments

Research has been carried out in a number of other areas, including further development of the permanent scatter and corner reflector InSAR methods (Chen et al.,2006; Chen et al.,2007a; Chen et al. 2007b), the study on the methods for SAR image co-registration, and development of quality measures for InSAR measurements.

A great number of case studies have been carried out with the InSAR technology, including studies of ground subsidence (Chen et al., 2007a), ground deformations in mining areas, slope deformations, crustal deformations, and glacier variations in the Antarctic.

3. REPORT OF TF 6.1.4 – MEASUREMENTS AND ANALYSIS OF CYCLIC DEFORMATIONS AND VIBRATIONS

The Task Force 6.1.4 was established in 2002. This report has been compiled from information submitted by Dr. Gethin Roberts, Chair (e-mail: gethin.roberts@nottingham.ac.uk)

3.1 Objectives

The objectives of this task force are: (1) to establish techniques to enable cyclic deformations to be measured and analysed and (2) development of links and collaboration between various research centres to optimize the technology for monitoring cyclic deformations and structural vibrations.

3.2 Activity 2006-2008

The structures currently under observation are bridges. A collaboration has been developed between University of Nottingham, University of Melbourn, and Brunel University. Also, a cooperation has been established between the TF6.1.4 and the FIG Working Group 6.4 through presentations and organising together sessions at:

- 2006: Bridges – Past, Present and Future, the First International Conference on Advances in Bridge Engineering, Brunel University, Uxbridge, UK, and

- 2007: 5th International Conference on Current and Future Trends in Bridge Design, Construction and Maintenance, Beijing China, September 2007.

The research continued at University of Nottingham, whereby kinematic GPS, servo driven total stations, accelerometers and pseudolites are being used to measure dynamic deformations of structures. The research has focussed on two areas. Firstly, the gathering and processing of GPS data from the Forth Road Bridge (Meng et al., 2007; Brown et al., 2007). These results have been presented in various conferences (Roberts et al. 2006a; Roberts et al., 2006b; Roberts et al. 2007). Secondly, the gathering and processing of GNSS data from a motorway viaduct. Preliminary results will be presented at the Symposium in Lisbon.

The research at Melbourne University, Australia had previously focussed on the Westgate Bridge (Raziq and Cornell, 2007). Since then they have been looking at the problem of satellite occlusion through the combination of data from multiple antennae.

4. REPORT OF TF 6.1.5 – USE OF LASER SCANNRS

The Task Force 6.1.5 was established in 2003. This report has been compiled from information submitted by Dr. Maria Tsakiri, Chair,(e-mail: mtsakiri@central.ntua.gr).

4.1 Objectives of TF 6.1.5

The aim of the Task Force is to advance the use of terrestrial laser scanning for geometric documentation and deformation monitoring in a variety of environments. Further objectives include the integration of laser scanning measurements with other measuring techniques, such as conventional geodetic systems and photogrammetric techniques. An important aspect of the group is to investigate quality control and metrological aspects of commercial laser scanners.

4.2 Activity 2006-2007

Over the last two years, the activity focused on the assessment of the sensitivity of laser scanning technology in the measurement of small scale deformation projects. Tsakiri et al. (2006) discuss the issues influencing the feasibility of laser scanning for deformation monitoring and the importance of evaluating the scanner's performance within a calibration scheme using independent procedures as well as self calibration measures depending on the scanner system. Lemmi et al. (2006) describes the use of laser scanning in measuring surface displacements in an experimental tunnel throughout and after its excavation. The reliability of the method has been assessed by comparing displacement measurements provided by the laser scanner with those calculated from total station surveying of markers installed on the tunnel surfaces. In van Gosliga et al. (2006) a measurement procedure using laser scanning is developed and tested to detect deformations in a bored tunnel. For this procedure first the tunnel model is fitted to a point cloud consisting of several registered terrestrial laser scans using a linearized iterative least squares approach which results in approximately optimal values for the tunnel model. Then deformations with respect to this tunnel model or between epochs are determined by means of a statistical testing procedure. Finally, in Gounaris & Tsakiri (2007) the use of terrestrial laser scanning technology in detecting slope deformations in open-pit mines is presented. An approach of processing the point cloud data in a 3D manner, without performing modeling, is presented where the real rotation and translation vectors of the deforming slope areas are estimated between measuring epochs.

Other recent activities of the TF include
- development of methods of calibration of laser scanners and
- assessment of laser scanner instruments in terms of their data quality.

Lichti (2007) presents a rigorous method for terrestrial laser scanner self-calibration using a network of signalised points. Lichti & Jamtsho (2006) address the issue of laser scanner's spatial resolution which is necessary in order to prevent aliasing and estimate the level of detail that can be resolved from a scanned point cloud. Kosmas et al. (2007) present the influence of reflectivity and examine whether the reflection due to surface material and colour contributes to measurement error.

5. REPORT OF TF 6.1.6 – ANALYSIS OF CRUSTAL DEFORMATION DATA

The Task Force 6.1.6 was established in 2003. This report has been compiled from information submitted by Dr. Stiros Stathis, Chair (e-mail: stiros@upatras.gr)

5.1 Objectives and Scope of Work

A main objective of this task force is to improve techniques to analyze historical geodetic data in comparison with modern techniques, mostly GPS-based. This is expected to permit:

1. To extend the geodetic information on crustal deformation in larger time and space scales; especially to compare data collected after a certain event (for instance an earthquake) with those collected before it in areas not covered yet by extensive GPS networks.
2. To examine whether the pattern of crustal deformation derived from longer term data (tens to hundreds of years) differs from the short-term one, derived mainly from modern, usually satellite data. This investigation is not limited to tectonic and seismic effects (especially the local earthquake cycle) but extends also to volcanic effects.

These aims require:

- identification and evaluation of the accuracy of historical records,
- understanding of the history of old benchmarks (since for instance, reconstruction of triangulation pillars sometimes leads to shifting of geodetic stations),
- development of cost-effective techniques to resurvey conventional and historical monuments,
- development of methods to compare such inhomogeneous data and efforts for preservation of historical geodetic records and monuments.

All these activities are case-sensitive because conditions in each case are far from uniform in both time and geographical scale.

5.2 Activity

Since 2003, the activity of TF 6.1.6 has attracted a gradually growing group of scientists from different countries (currently from UK, France, Italy, Bulgaria, Turkey, USA, Germany, Romania, Greece, Egypt) with contacts from several other countries.

There has been an effort to examine a few case studies which were expected to provide some first significant results.

a) In cooperation with colleagues from University Paris XII historical levelling benchmarks in a plain in Northern Greece have been investigated and surveyed with GPS in order to study ground subsidence phenomena, as well as the accuracy of historical surveys and the adaptation of methods for quick measurements with accuracy compatible with that of historical surveys (Psimoulis et al., 2007)

b) Comparison of historical surveys and of historical surveys with GPS data have been made in two other areas in Greece, in order to investigate ground subsidence due to water pumping and earthquake effects.

c) In cooperation with UNAVCO and Georgia Tech (USA) a continuous GPS network plus campaign sites have been established in the Santorini volcano, in an area covered in the past by an EDM network showing temporal caldera inflation (Newman et al., 2007).

d) Some peculiarities of the earthquake cycle in the evaporite environment of Ionian Sea-Adriatic Sea have been studied using data collected in the framework of a GPS network established and repeatedly measured by Swiss, Greek and other colleagues (Stiros, 2005).

e) In the framework of the Central European Regional Geodynamic Project-CERGOP-2 there have been two GPS campaigns across Central Europe and parts of the Balkans. Unfortunately, this activity was interrupted in 2006.

f) Analysis of tide-gauge and of coastal biological data was made in collaboration with French colleagues in order to assess the accuracy of the latter to define accurate estimates of seismic coastal movements in areas distant from tide-gauges or other geodetic stations.

The aims of the Task Force, data collected and results obtained were presented at several meetings in Greece, Germany, France, Italy, Turkey. In the Perugia IUGG 2007 Congress and in particular at an IAG Symposium there has been an important participation and there was much interest, especially from Japanese people.

6. REPORT OF TF 6.1.7 – CONTINUUM MECHANICS AS A BASIS FOR DESIGN AND ANALYSIS OF DEFORMATION MEASUREMENTS

The Task Force 6.1.7 was established in 2006. This report has been compiled from information submitted by Dr. Anna Szostak-Chrzanowski, Chair (e-mail: amc@unb.ca)

6.1 Objectives

The main objective of the Task Force is to unify terminology and methods of analysis applied by specialists in various fields of engineering and geo-science in solving problems in monitoring and analysis of deformation in engineering and geoscience projects using principles and laws of continuum mechanics ((Szostak-Chrzanowski et al., 2006).

To reach the objective, the following scope of work has been proposed by the TF:

1. Evaluation of the need for the development of interdisciplinary approach to deformation analysis of any type of deformable body which includes geometrical analysis and physical interpretation.
2. Development of uniform terminology based on the continuum mechanics terminology
3. Review of the continuum mechanics laws as a base of the interdisciplinary approach to deformation analysis
4. Review of deterministic modelling with concentration on finite element method
5. adaptation of strain theory based on continuum mechanics to robust analysis of geodetic networks
6. Use of the deterministic modelling in the design of monitoring networks (discrete and continuous fields)
7. Review of applications of integrated analysis (engineering and natural structures)
8. Education

6.2. Activity 2006-2008

At present, the Task Force includes scientists from Canada, Poland, and PR of China.
During the reporting period, activities of the Task Force 6.1.7 concentrated on:

- Adaptation of strain theory based on continuum mechanics to robust analysis of geodetic networks (Gambin et al., 2008),

- Integrated analysis of Shuibuya Dam constructed in China (Szostak-Chrzanowski et al., 2008). Shuibuya dam is the largest in the world Concrete Face Rockfill Dam CFRD (233m high). The analysis followed the earlier works by Szostak – Chrzanowski and Massiéra (2006) and Massiéra at al., (2007).
- Integrated analysis of ground subsidence due to mining activity and hydrological changes (Szostak-Chrzanowski and Chrzanowski, 2008) and
- Applications of deterministic modelling for the design of monitoring schemes

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Corresponding author contacts

Adam CHRZANOWSKI
adamc@unb.ca
University of New Brunswick
Canada