GOALS AND ACHIEVEMENTS OF FIG WORKING GROUP WG6.1- DEFORMATION MEASUREMENTS AND ANALYSIS

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Abstract

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. The main goals of WG 6.1 are: 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 measurements.The dissemination of knowledge is achieved by organising international symposia and technical sessions at FIG Congresses related to deformation measurements. Since 1975, WG6.1 has organised eleven international symposia in Poland, Germany, Hungary, Canada, Hong Kong, USA, and Greece. In 1978, an *ad hoc* committee (Task Force 6.1.1) was created to solve problems in geometrical deformation analysis. Practically, all problems of geometrical analysis of deformation measurements were solved by that committee. The final report was presented at the FIG Congress in Toronto, Canada, in 1986. Since 1988 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. 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. At the FIG Congress in Washington, D.C., in 2002, two new task forces were established:
• Task Force 6.1.3 on Optimal Use of Interferometric Synthetic Aperture Radar (InSAR); and
• Task Force 6.1.4 on Monitoring and Analysis of Cyclic Deformations and Structural Vibrations.

1. Introduction

The whole universe, including our planet Earth with all its infrastructure, is deforming. There are endless applications for new developments in monitoring and analysis of deformations (Chrzanowski, 1994). Safety, economical design of man-made structures, efficient functioning and fitting of structural elements, environmental protection, and development of mitigative measures require good understanding of causative factors and mechanism of deformations, which can be achieved only through proper monitoring and analysis of deformable objects. Development of new methods and techniques for monitoring and analysis of deformations and development of methods for the optimal modelling and prediction of deformation are subject of intensive studies of many professional groups which, besides survey engineers, photogrammetrists, and geodesists, include structural, mining, geotechnical, and mechanical engineers, as well as geophysists, physicists, and geologists.

The FIG Working Group 6.1 on Deformation Measurements and Analysis has always been one of the most vital groups of FIG Commission 6 (Engineering Surveys) and one of the most, if not the most, active international groups dealing with the problems of monitoring and analysis of deformation measurements. Besides the activity of FIG WG6.1, there are a number of other international groups, which are involved in deformation studies. Among the major organizations one should list:

- International Association of Geodesy (IAG) with very active study groups concerning geodynamics, tectonic plate movements, and earth's crust deformations,
- International Society for Photogrammetry and Remote Sensing (ISPRS) within the activity of Commission 5 on Close Range Photogrammetry and Vision Systems,
- International Society for Mine Surveying (ISM) with their very active Commission 4 on Ground Subsidence and Surface Protection in mining areas,
- International Society for Rock Mechanics (ISRM) with their overall interest in rock stability and ground control,
- International Commission on Large Dams (ICOLD),
- International Society of Soil Mechanics and Foundation Engineering, and
- International Association of Hydrological Sciences (IAHS) which organizes international symposia on ground subsidence due to the withdrawal of underground liquids (water, oil, etc.).

Most of the activities and studies of the above groups focus on direct applications to their particular deformation problems. The activity of FIG WG6.1, particularly of the last 15 years, has been focused on developing new methods and techniques, which could be applied to monitoring and analysis of any type of deformable bodies, using any type of deformation measurements (using geodetic and/or geotechnical/structural instrumentation). Thus the activity of WG6.1 has always been of an interdisciplinary nature. Although accuracy and sensitivity criteria for determination of deformation may considerably differ between various applications, the basic principles of the design of the monitoring schemes and their geometrical analysis remain the same whether one is concerned with the earth crust deformations, slope stability, dam deformations, or displacements of magnets in accelerators of sub-atomic particles.

The Working Group 6.1, originally known as the Study Group C of FIG Commission 6 was established in 1969 under the name: Measurements of Deformations and the Automation of Measurement Process. The group was created at the initiative of the late Professor T. Lazzarini of the Warsaw Technical University, who became the first chairman of the group. Between 1975 and 1986 the group was led by the late Professor A. Platek of Poland. Since 1986, the group has been chaired by Professor A. Chrzanowski of the Canadian Centre for Geodetic Engineering at the University of New Brunswick. Initially, the main tasks of the group was to organize and to extend the international collaboration in the field of deformation measurements by geodetic methods. Since 1986, the tasks have been extended beyond the use of geodetic methods into other monitoring techniques and into interdisciplinary analysis and interpretation of deformations. Recently, the name of the group has been changed into Working Group 6.1 on Deformation Measurements and Analysis.

Since the very beginning the Working Group 6.1 has played a very important role in providing a forum for the exchange of information on the new developments by organizing technical sessions during the FIG Congresses and, more important, by organizing specialized international symposia and workshops on deformationmeasurements. Besides organizing the international symposia, WG6.1 calls on *ad hoc* committees (task forces) to solve special problems of the deformable world through international cooperation between various research centres.

This report presents a review of the major events and achievements of WG6.1 between 1969 and 2003 with a focus on the scope of work of two new task forces, which were created at the FIG Congress in Washington, D.C. in 2002.

2. Review of Major Events and Achievements of WG 6.1

Since 1986, the main tasks and goals of the WG6.1 are:
(1) to disseminate knowledge and exchange information on new developments in deformation monitoring and analysis;
(2) to stimulate international co-operation in solving specific (*ad hoc)* problems related to deformation studies; and
(3) to promote multidisciplinary approach to integrated monitoring and interpretation of deformations in engineering and geoscience projects.

The first goal is achieved by organizing technical sessions on deformation measurements at FIG Congresses and organizing international symposia and workshops. The second goal is achieved by organizing international *ad hoc* committees (Task Forces) consisting of specialists from selected research centres who concentrate on investigating and solving some identified problems related to deformation studies. The third goal is achieved by inviting specialists from various fields of engineering and geosciences to participate in the activities of the WG6.1.

Between 1975 and 2003, WG6.1 organized 11 symposia and co-sponsored two major workshops. They are listed below in a chronolgical order :

1975: 1st Int. Symposium on Deformation Measurements by Geodetic Methods hosted by the Techn. University of Mining and Metallurgy, Krakow, POLAND, Sept. 22-24 (chaired by Prof. A. Platek);

1978: 2nd Int. Symposium on Deformation Measurements by Geodetic Methods hosted by the University of Bonn, Bonn, GERMANY, Sept. 25-28 (chaired by: Prof. L. Hallermann);

1982: 3rd Int. Symposium on Deformation Measurements by Geodetic Methods hosted by the Hungarian Geodetic and Cartographic Society, Budapest, HUNGARY, August 25-27 (chaired by Prof. A. Detreköi);

1985: 4th Int. Symposium on Deformation Measurements by Geodetic Methods hosted by the Polish Society of Surveyors and Geodesists, Katowice, POLAND (chaired by Prof. W. Janusz);

1986: Deformation Measurements Workshop hosted by Massachusetts Institute of Technology, Cambridge, MA, USA, 31 October - November 1 (chaired by Dr. Y. Bock)

1988: 5th Int. Symposium on Deformation Measurements hosted by the University of New Brunswick, Fredericton, N.B., CANADA, June 6-9 (chaired by Prof. A. Chrzanowski);

1992: 6th Int. Symposium on Deformation Measurements hosted by the University of Hannover, Hannover, GERMANY, February 24-28 (chaired by Prof. H. Pelzer);

1993: 7th Int. Symposium on Deformation Measurements hosted by the University of Calgary, Banff, Alberta, CANADA, May 3-5 (chaired by Prof. W. Teskey);

1994: Perelmuter Worshop on Dynamic Deformation Models hosted by Technion Israel Inst. of Technology, Haifa, ISRAEL, August 29 – September 1 (chaired by Prof. H. Papo);

1996: 8th Int. Symposium on Deformation Measurements hosted by the Hong Kong Polytechnic University, Kowloon, HONG KONG, June 25-28 (chaired by Prof. Y.Q. Chen);

1999: 9th Int. Symposium on Deformation Measurements hosted by the University of Warmia and Mazury, Olsztyn, POLAND, September 27-30 (chaired by Prof. A. Wasilewski);

2001: 10th Int. Symposium on deformation Measurements hosted by the Metropolitan Water District of South California, Orange, California, USA, March 19-22 (chaired by C. Whitaker);

2003: 11th Int. Symposium on Deformation Measurements hosted by the Patras University, Santorini Island, GREECE, May 25-28 (chaired by Prof. S. Stiros).

The published proceedings of the above symposia and workshops provide an enormous wealth of information on the development of new techniques and new methods in monitoring and analysis of deformations.

In the late 1970s and early 1980s, WG 6.1 concentrated their efforts on the development of new monitoring techniques and on geometrical analysis of geodetic deformation surveys. It was reflected in the content of the papers presented at the FIG symposia in Krakow in 1975 and in Bonn in 1978. At that time, the main problem of the deformation analysis was the identification of unstable reference points in geodetic monitoring networks. Several approaches were proposed by different authors. As a result, an *ad hoc* Committee on Deformation Analysis (Task Force 6.1.1), chaired by A. Chrzanowski, was established at the symposium in Bonn with a task of comparing different approaches and developing a unified theory for the geometrical analysis of deformation surveys. Initially, six research centres (University of New Brunswick in Canada, Universities of Karlsruhe, Hannover, Stuttgart, and Munich in Germany, and Delft in the Netherlands). joined the work of the committee. Eleven other centres joined the committee work after the 3-rd symposium in Budapest. The work of the Committee was summarized in three published progress reports (Chrzanowski et al., 1981; Heck et al., 1982; Chrzanowski and Secord, 1983) and several internal reports with a final report (Chrzanowski and Chen, 1986) presented at the 13-th International Congress of FIG in Toronto in 1986 (the report is available at: http://ccge.unb.ca) . The work of the *ad hoc* committee resulted, among others, in solving the problem of the identification of unstable reference points by using either:

• the method based on the congruency test of the quadratic forms of residuals of displacements obtained from least squares adjustment of single epochs of repeated observations vs. combined two-epoch adjustment (Pelzer 1974; Niemeier1981; Gründig et al. 1985) or

• the method based on the Iterative Similarity Weighted Transformation (IWST) of displacements until the sum of absolute displacement components of the reference points becomes minimum (Chen, 1983; Chen et al., 1990).

The most important outcome of the study by the *ad hoc* committee was the development of the *generalised method of geometrical deformation analysis* (Chen 1983; Chrzanowski et al., 1983; Chrzanowski et al., 1986a) that allows for using any type of deformation measurements (geodetic techniques and geotechnical/structural instrumentation), even if scattered in space and time, in a simultaneous geometrical analysis of deformation measurements and modelling of displacement and strain fields. The modelling is obtained by a statistically best fitting of a selected displacement function (deformation model) into the observation data. Some additional comments on the geometrical modelling are given in (Chen and Chrzanowski, 1996). The IWST is a part of the generalised method in analysing the deformation trend. The method has found a number of applications in dam deformation analyses (eg., Chrzanowski et al. 1989;

Chrzanowski et al., 1991), in ground subsidence studies (e.g. Chrzanowski et al., 1986b) and in tectonic plate movements (e.g., Chrzanowski et al. 1983).

During the 5th symposium held in Canada in 1988, a general agreement was reached that all basic problems of the geometrical analysis had been solved and no further international cooperation in that area was needed. At the same time, a recommendation was made that WG6.1 should become more active in an interdisciplinary approach to the physical interpretation of deformation measurements, particularly in the aspects of an optimal combination of the geometrical analysis with deterministic modelling of the load-deformation relationship for the purpose of a better understanding of the mechanism of deformations (see, e.g. Chrzanowski et al., 1990; Chrzanowski and Szostak-Chrzanowski, 1993;). The 5th symposium was the first in the series of the FIG symposia that besides geodetic engineers,the symposium was attended by many top specialists in other fields of engineering and geosciences.

During the XIXth FIG Congress in Helsinki in 1990, those interested in the work of the Working Group 6.1 met to discuss the status and plans for the future activities of the Group. The discussion focused on the problem of the interdisciplinary approach to integrated monitoring and analysis of deformations concluding, among others, that:

(1) The procedures developed within FIG should be made known to the general surveying and geodetic communities and to other professionals interested in the deformation analysis through interdisciplinary symposia, courses, and publications.
(2) Contacts and exchange of views with specialists from other professions such as geotechnical and structural engineering, soil and rock mechanics, geophysics, and engineering geology, should be intensified by inviting them to the symposia and workshops organized by FIG.
(3) Geodetic engineers and scientists, in order to successfully compete with other professionals involved in deformation monitoring and analyses, should get acquainted with the deterministic and statistical modelling of load-deformation relationship as well as with geotechnical and structural monitoring techniques.

The growing interest among geodetic engineers in the interdisciplinary approach to the integrated analysis and physical interpretation of deformations brought a confusion into the terminology used in deformation modelling. In 1992, at the 6th Symposium in Hannover, some authors became confused with the use of the terms such as dynamic or kinematic models of deformation, deterministic vs. statistical, or parametric vs. non-parametric modelling etc. The main confusion arose from the fact that some authors did not distinguish a difference between modelling the load-deformation relationship and geometrical (descriptive) analysis of the observed deformation As a result, another *ad hoc* committee (Task Force 6.1.2) was created in Hannover to look into the terminology and classification of deformation models. After 8 years of work, and after several progress reports and many changes in the membership of the committee, Welsch and Heunecke (2001) presented the final report on the proposed terminology at the 10th Symposium in California. The report, under the title of "Models and Terminology for the Analysis of Geodetic Monitoring Observations" is available from FIG as FIG Publication No. 25 (May 2001).

Starting with the 5th Symposium in 1988, the input of specialists in other fields of engineering into the activity of WG6.1 has become very significant. The role of the monitoring surveys, which used to serve only the determination of the change in shape and dimensions of deformable bodies has expanded into verification of material parameters, determination of causative factors, and determination of deformation mechanism (see, e.g., Szostak-Chrzanowski et al., 2003).

Recent developments in a full automation of monitoring surveys (see e.g., Duffy et al. 2001) and in new technologies such as Interferometric Synthetic Radar (InSAR), pseudolites, laser

scanners, create new applications in the deformable world and need for further studies.At the FIG Congress in Washington, D.C., in 2002, two new task forces were established:
• Task Force 6.1.3 on Optimal Use of Interferometric Synthetic Aperture Radar (InSAR); and
• Task Force 6.1.4 on Monitoring and Analysis of Cyclic Deformations and Structural Vibrations.

3. New Task Forces

3.1 T ask Force 6.1.3 –Use of Interferometric Synthetic Radar (InSAR)

The Task Force 6.1.3: Use of Satellite Radar Interferometry in Deformation Measurements was formed at the XXII FIG Congress in Washington in 2002 in recognition of the importance of the technology in measuring deformations, to further develop the technology and to apply the technology to study the various types of deformations. Dr. Xiaoli Ding of the Hong Kong Polytechnic University was elected as the leader of the new Task Force.

Interferometric synthetic aperture radar (InSAR) has become one of the most important technologies for measuring the deformations of the earth surface. Since the first large-scale validation of the technology to observe crustal deformations associated with the 1992 Landers earthquake (Massonnet, 1993), InSAR has been increasingly applied to study deformations associated with, for example, earthquakes (e.g., Zebker et al, 1994; Massonnet et al., 1996; Tobita et al., 1998; Baer et al., 1999; Fujiwara et al., 2000; Kontoes et al., 2000; Fialko et al., 2001), land settlement (e.g., Gabriel et al., 1989; Massonnet et al., 1997; Galloway et al., 1998; Fruneau and Sarti, 2000; Bawden et al., 2001; Liu et al., 2001), and volcanic eruptions (e.g., Massonnet et al., 1995; Jonsson et al., 1999; Stevens et al., 2001).

Despite the widely reported success of InSAR in measuring deformations, there are still significant difficulties associated routine applications of the technology. The difficulties include the effects of the atmosphere on the propagation of radar signals and the so-called temporal/spatial decorrelation and shadowing/overlapping of images in steep and heavily vegetated areas, or in urban areas with dense buildings of mixed heights. Further work is therefore necessary to enhance the accuracy, reliability and usefulness of the technology. Besides, many application fields of both scientific and practical significances are yet to be explored.

The Terms of Reference of the Task Force are:

- Development, test and standardization of algorithms, software and procedures for measuring deformations with InSAR;
- Study of accuracy, reliability and sensitivity of InSAR measurements under various atmospheric, field and imaging conditions;
- Characterizing and mitigation of atmospheric effects on InSAR measurements;
- Integration of InSAR with other deformation measurement methods;
- Study of deformations related to various engineering and geophysical problems.

The Task Force will

- Carry out test campaigns using data sets of selected sites;
- Conduct focused research in areas of importance;
- Organize conferences/workshops;
- Facilitate discussions, exchange of results and research collaboration among members; and
- Involve in other activities of relevance if and when necessary.

The current (2003) membership of the Task Force includes 12 researchers from various centres in Australia, Canada, China, Hong Kong, Japan, Netherlands, and U.K.

A number of the members attended the XXII FIG Congress in Washington and the Advanced Workshop on InSAR for Measuring Topography and Deformation of the Earth Surface held during December 16-17, 2002 in Hong Kong, and presented papers covering a variety of research topics relevant to the Task Force. A special session on InSAR has been organised for the 11th International Symposium on Deformation Measurements. A special workshop on InSAR is planned by the Task Force 6.1.3 to be organized in the middle of 2004. Those, who wish to participate in the work of the Task Force should write to Dr. Ding at: lsxlding@polyu.edu.hk

3.2 Task Force 6.1.4 on Measurements and Analysis of Cyclic Deformations and Structural Vibrations

This task force was established at the FIG Congress in Washington in April 2002. The task force looks at cyclic deflections of structures rather than long term deformations. Dr. Gethin Roberts of Nottingham University was elected to lead the international task force.

Interest has been shown in this task force by various members of the FIG, and contacts have been established. One of the main aims of this task force is to establish techniques to enable cyclic deformations to be measured and analysed. This type of work is already underway at the University of Nottingham, whereby kinematic GPS, servo driven total stations, accelerometers and pseudolites are being used to measure dynamic deformations of structures. Research into this area was first started at the IESSG in 1996 [Ashkenazi *et al*, 1996]. The type of structure currently under observation are bridges. This work is currently funded by the UK's Engineering and Physical Sciences Research Council under a joint project with Cranfield University entitled "A Remote Health Monitoring System Using Computational Simulation and GPS Sensors". In addition to the two research centres, Railtrack, W S Atkins and Pell Frishmann are also involved with this half a million pound research project. The results from this project are presented at the various relevant FIG meetings.

Further work at the IESSG now includes a project investigating the use of similar instruments to monitor the horizontal deflections of tall structures. One of the main problem areas with this application is the effect of the troposphere upon the reference and rover GPS receiver located at different altitudes [Roberts *et al*, 2001].

Furthermore, the FIG meetings allow researchers from all over the world to gather and discuss various issues concerning the work. Consequently, individual links are firmed and research collaboration is established. For example, there has been a great deal of collaborative research and exchanges with the University of Nottingham and the University of New South Wales [Dodson *et al*, 2003]. It is hoped that more similar collaboration will be established and encouraged through the FIG meetings. This means that such work will not simply concentrate within the FIG meetings themselves, but will expand outside of the meetings, and will then report back to the meetings and conferences through paper presentations.

Members of this task force attended the IAG/FIG conference in Berlin in May 2002, and presented a variety of papers relevant to the field. Again, this was a good meeting and opportunity to talk with more colleagues about the variety of international work.

A variety of papers on this subject are in the programa of the 11th Symposium in Santorini in May 2003.

A workshop will be held at Nottingham during 28 to 30 June 2004. This will be in conjunction with a meeting of Working Group 6.4. It is anticipated that the attendees will be more than just surveyors, and will include structural engineers and other people interested in this type of work. Those interested in joining the work of the Task Force 6.1.4 should write to Dr. Roberts at: gethin.roberts@nottingham.ac.uk

The aims of the task force are:

- To develop, test and standardise algorithms, software and procedures for measuring cyclic deformations;
- Study of the required and achievable accuracy through various measuring techniques;
- Characterisation and mitigation of atmospheric and regional effects, such as GPS multipath;
- Integration of GPS and other sensors into a combined system;
- Organise and be involved in conferences and workshops;
- Work closely and integrate the work and methods into the engineering community, thus opening up the group to more than just surveyors;

4. Conclusions

The activity of the FIG Working Group 6.1 on Deformation Measurements and Analysis fulfils the expectations. So far, the goals are being achieved. Technical sessions at the FIG Congresses and frequent symposia provide a venue for the exchange of information and dissemination of new developments. The WG6.1 has stimulated the international cooperation in the development of new methods and techniques in deformation studies. The Working Group 6.1 has become a truly interdisciplinary study group.

The current activity of WG6.1, concentrates on the automation of deformation surveys, use of Synthetic Aperture Radar (SAR) in interferometric determination of displacements, monitoring and analysis of structural vibrations and cyclic deformations, and physical interpetation, modelling, and prediction of deformations. Through the interdisciplinary approach to deformation studies, the FIG Working Group 6.1 links surveying and geodetic specialists with specialists in structural, mining, geomechanical, and geophysical disciplines.

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