A WEB-BASED SYSTEM FOR DEFORMATION MONITORING

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Abstract: In late 2006, a new three-year NSERC (Natural Sciences and Engineering Research Council of Canada) CRD (Collaborative Research and Development) project on "Intelligent Structural Monitoring" was begun in the Department of Geomatics Engineering, Schulich School of Engineering at the University of Calgary. This research project is a collaboration of industry and university partners. The industry partners are Sarpi Ltd. (Dr. Robert Radovanovic, NSERC CRD Co-Investigator) and Terramatic Technologies Inc. (Bill Lovse, NSERC CRD Co-Investigator). The university partners are Dr. Bill Teskey (Principal Investigator), Dr. Naser El-Sheimy (Co-Investigator), and Axel Ebeling (Project Manager). The first objective of the "Intelligent Structural Monitoring" NSERC CRD Project is to develop new, more efficient, and more reliable methods for deformation monitoring. The second objective is to develop a web-based system for deformation monitoring.

This paper deals with the development and application of the web-based system for deformation monitoring. In Summer 2007, the first version of the web-based system was ready for launch. The system allows for on-site analysis of original and repeated observations, with these observations coming from total stations, precise levelling equipment, GPS/GNSS satellite receivers, terrestrial laser scanners, or other sensors. From the analysis of these observations, three-dimensional movements can be determined.

1. INTRODUCTION

The idea for a web-based system for deformation monitoring came from deformation survey projects undertaken in the last five years. It was realized that the development of new, more efficient and more reliable methods for deformation monitoring should include the development of a web-based system to process deformation measurements and archive the results.

One such project was deformation monitoring of the roof of the Olympic Speedskaing Oval in Calgary (Teskey et al. 2006, Teskey et al. 2005, Teskey et al. 2004). Figure 1(a) shows a cross-section through the Olympic Oval and Figure 1(b) shows the west elevation. In this project, summer to summer seasonal movements of 58 points in the Olympic Oval roof structure were determined to a standard deviation of about 1mm.

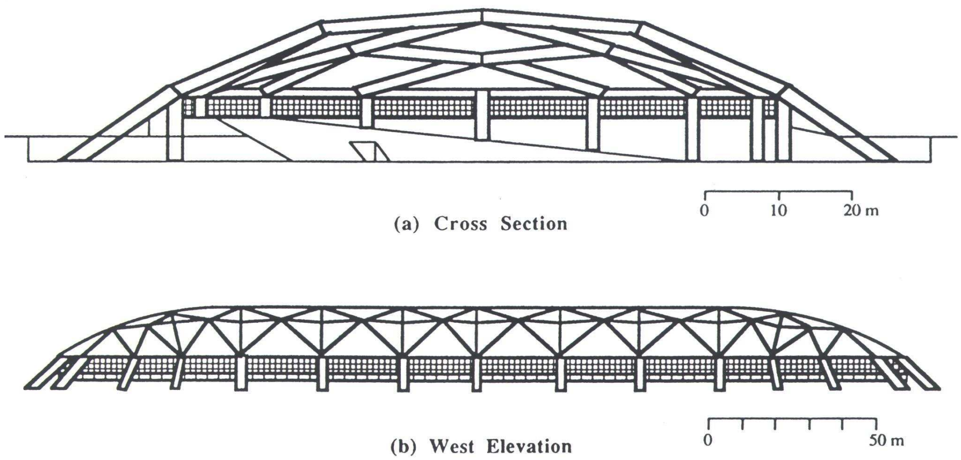

Figure 1 – Olympic Oval, Calgary

Another more recent deformation monitoring project was undertaken in 2006/2007. In this project, fall to winter seasonal movements of 8 points in the superstructure of an overpass (see Figure 2) were determined to a standard deviation of about 2.5mm.

Figure 2 – Overpass at Nose Hill Drive and Crowchild Trail, Calgary

In the following sections, the web-based system for deformation monitoring and its application in two new deformation monitoring projects is described.

2. WEB-BASED SYSTEM FOR DEFORMATION MONITORING

The Home Page of the Web-Based System for Deformation Monitoring is shown in Figure 3.

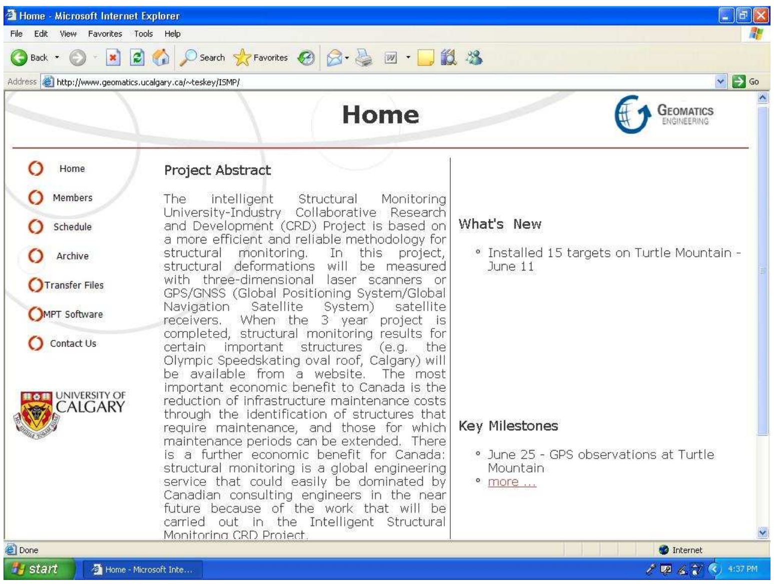

Figure 3 – Home Page of Web-Based System for Deformation Monitoring

The item labelled "MPT Software" on the left side of the Home Page refers to a multi-parameter transformation relating original and repeated observations between an instrument station (e.g. total station or three-dimensional laser scanner) and any number of target points. The transformation consists of a 6-parameter similarity transformation at the instrument station (translations in the X-, Y- and Z-directions at the instrument station, and rotations about the X-, Y- and Z-axes at the instrument station), plus a scale factor relating original and repeated instrument-target slope distance observations (or derived slope distance observations), plus a refraction correction between original and repeated zenith angle observations (or derived zenith angle observations).

This mathematical model can be expressed as follows:

$$X_O = \lambda(X_R + \kappa Y_R - \varphi Z_R) + T_x \quad (1)$$

$$Y_O = \lambda(-\kappa X_R + Y_R + \omega Z_R) + T_y \quad (2)$$

$$Z_O = \lambda(\varphi X_R - \omega Y_R + Z_R) + T_z \quad (3)$$

with $X_R = S_R \sin H_R \sin(V_R + (\Delta R)S_R)$ (4)

$Y_R = S_R \cos H_R \sin(V_R + (\Delta R)S_R)$ (5)

$Z_R = S_R \cos(V_R + (\Delta R)S_R)$ (6)

$X_O = S_O \sin H_O \sin V_O$ (7)

$Y_O = S_O \cos H_O \sin V_O$ (8)

$Z_O = S_O \cos V_O$ (9)

in which H_O, V_O and S_O are original horizontal circle, vertical circle (zenith angle) and slope distance observations (or derived observations) respectively;

H_R, V_R and S_R are repeated horizontal circle, vertical circle (zenith angle) and slope distance observations (or derived observations) respectively;

X_O, Y_O and Z_O are X-, Y- and Z-coordinates computed from the original observations;

X_R, Y_R and Z_R are X-, Y- and Z-coordinates computed from the repeated observations;

T_x, T_y and T_z are X-, Y- and Z-translations respectively at the instrument station;

ω, φ and κ are rotations about the X-, Y- and Z-axes respectively at the instrument station;

λ is the scale factor relating original and repeated slope distance observations; and ,

ΔR is the refraction correction (in arc seconds per metre of slope distance) relating original and repeated zenith angle observations (or derived observations).

The set of equations (1) through (9) inclusive can be solved as an implicit nonlinear least squares adjustment to obtain the transformation parameters ω, φ, κ, T_x, T_y, T_z, λ and ΔR; corrected observations H_O, V_O, S_O, H_R, V_R and S_R to each target point; and movements (X_T - X_O), (Y_T -Y_O) and (Z_T - Z_O) of each target point.(X_T, Y_T and Z_T are transformed X-, Y- and Z-coordinates as given by the right-hand-sides of Equations (1), (2) and (3) respectively.)

In Fall 2007, the formulation of the Multi-Parameter Transformation given in equations (1) to (9) inclusive was generalized so that it could easily be applied to large-scale deformation monitoring networks with mixed observation types (e.g. total station observations and DGPS baseline observations), and with a very small number of network points being stable between measurement epochs. The generalized formulation is described in Ebeling et al.(2008).

3. TURTLE MOUNTAIN DEFORMATION MONITORING PROJECT

In May 2007, the Precise Engineering and Deformation Surveys (PEDS) Group in the Department of Geomatics Engineering at the University of Calgary started the new research project “Turtle Mountain Deformation Monitoring 2007” in collaboration with Alberta Geological Survey.

The goal of this research project is to detect movements in two areas of the mountain. The first area is the saddle between North Peak and South Peak (see right side of Figure 4) where the April 29, 1903 Frank Slide broke free. In this area the top of the mountain is cracked and fractured, and there is evidence of both seasonal and long term movements. The second area of interest is the previously unmonitored east-facing side of Turtle Mountain. There are no large slides or rockfalls on this part of the mountain, but there is evidence of long term movements, for example, curvature of tree trunks near ground level in the wooded lower slopes of the mountain.

Figure 4 – Turtle Mountain from the Northeast

A total of 15 structural steel target points were designed, fabricated and installed on Turtle Mountain in May 2007. The initial epoch of total station and DGPS observations were made in June 2007. The first repeated epoch of total station and DGPS observations were made in late September and early October 2007. To determine Summer 2007 to Fall 2007 movements, the MPT (Multi-Parameter Transformation) software was applied. The result: no movement at any of the 15 points at a level of detectability (standard deviation of computed movement) that varied from 5mm to 30mm.

4. DEFORMATION MONITORING AT AN INDUSTRIAL SITE

A large deformation monitoring network extending over two unstable slopes (North Hill and Rom Hill; see Figures 5(a) and 5(b)) near a cooling water pond for a coal-fired electric power generation plant was observed in 3 epochs: Summer 2005, Summer 2006 and Summer 2007. Total station and DGPS baseline observations were collected in all epochs.

Figure 5(a) – North Hill

Figure 5(b) – Rom Hill

To determine Summer 2005 to Summer 2007 movements, the MPT software was applied. The results: 6cm down-slope movement of points on North Hill (at a level of detectability of 1cm), and 5cm downward movement of points on Rom Hill (at a level of detectability of 2cm). A detailed description of the deformation analysis is given in Ebeling et al.(2008).

5. CONCLUSION

The web-based system for deformation monitoring developed in June 2007 for the NSERC CRD “Intelligent Structural Monitoring” Project has had limited use up to March 2008. It will be used extensively in Summer 2008 (for deformation monitoring projects described in

Sections 3 and 4) and Fall 2008 (for deformation monitoring project described in Section 3) because it allows for efficient and reliable on-site analysis of original and repeated measurement epochs to determine three-dimensional movements.

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