Interdisciplinary Approach to Design, Analysis, and Modeling of Deformation Surveys

Anna Szostak-Chrzanowski
and
Adam Chrzanowski

Canadian Centre for Geodetic Engineering

University of New Brunswick
Fredericton, N.B., Canada

Recent catastrophic disasters

- failures of levees and bridges in U.S.A.;
- collapse of highway overpasses in Canada;
- collapses of roofs of large civil structures in Germany, Poland, and Russia;
- land slides in California, Pakistan, and the Philippines;
- rock failures in deep coal mines in China and U.S.A.

At least some of the above disasters could have been avoided if proper monitoring systems had been installed

Deformation monitoring may provide advanced warning

There are
- over 45,000 large dams in the world.
- over 80,000 bridges in U.S.A. alone
- open pit mines
- slopes
- underground excavations

Monitoring of their behavior:
increases their safety,
prevents disasters

http://simscience.org/cracks/intermediate/mintro.html
(„Superman" movie)

Monitoring requirements to serve as a warning system

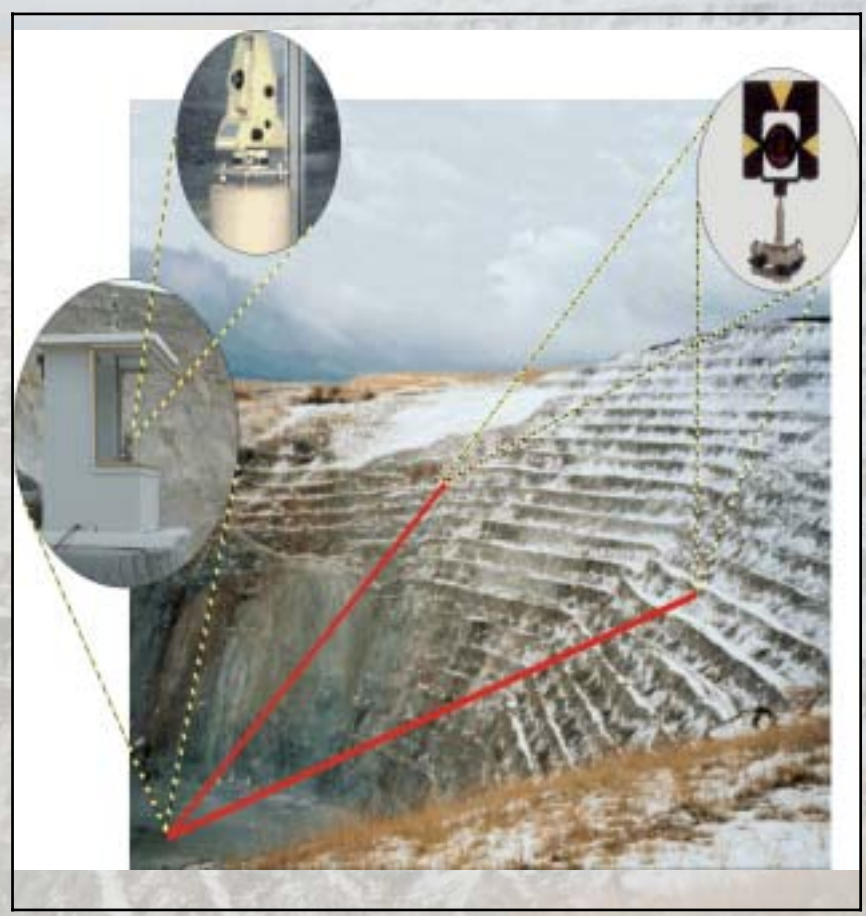
Fully automated and continuous

Sub-centimetre accuracy at 95%

Automatic triggering of alarm when threshold values of displacements, velocities, and/or accelerations are exceeded

Visualization of displacements in almost real time

Low cost



Current geodetic technologies

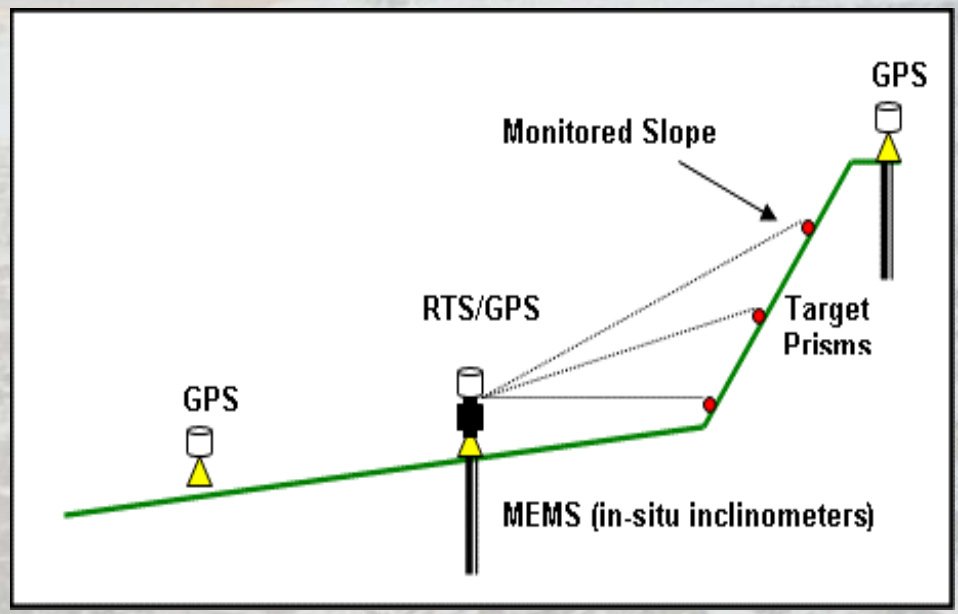
- GPS
- Robotic Total Stations (RTS)
- Laser Scanners
- Interferometric Synthetic Aperture Radar (InSAR),
- Digital Photogrammetry

- all are affected by atmospheric refraction and/or tropospheric delay and
- not all are suitable for fully automated and continuous monitoring

Geotechnical instrumentation

Tiltmeters, inclinometers, strainmeters, extensometers, strong motion sensors, based on Micro Electro-Mechanical Systems (MEMS)
(suitable for full automation and continuous data acqusition).

Once embedded within the structure, however, the geotechnical/structural instruments cannot be rechecked or recalibrated (i.e. they are less reliable than geodetic techniques)



Trend: Use of Integrated Multi-sensor Monitoring System

Emerging new monitoring technologies

- **Micro-Electro-Mechanical Systems (MEMS) - integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro-fabrication technology**
- **Distributed fibre-optics strainmeters (up to 10 km conduits) - a prototype at UNB**
- **Ground-based InSAR (two prototypes: in Australia and Italy) for continuous monitoring**

New developments at Canadian Centre for Geodetic Engineering

- **ALERT DDS software suite for fully automated multi-sensor monitoring**

- **PPMS software for fully automated monitoring with GPS augmented (if needed) with pseudo-satellites (terrestrial trasmitters of GPS-like signals)**

- **SCAN System for semi-automatic structural monitoring**

- **Deterministic modeling of deformations in the design of monitoring schemes**

- **Integrated analysis and physical interpretation of deformations**

ALERT Deformation Detection System (DDS) Software for fully automated multi-sensor monitoring

- Fully automated data acquisition, data processing, and visualization
- Triggering of alarm
- Identification of unstable reference points
- Least squares adjustment of RTS and GPS networks
- Self-recovery in case of power shortage

Currently, DDS works with RTSs and GPS

Examples of RTS and RTS/GPS shelters of the DDS system

a) at a large dam in California

b) in an open pit mine in B.C.

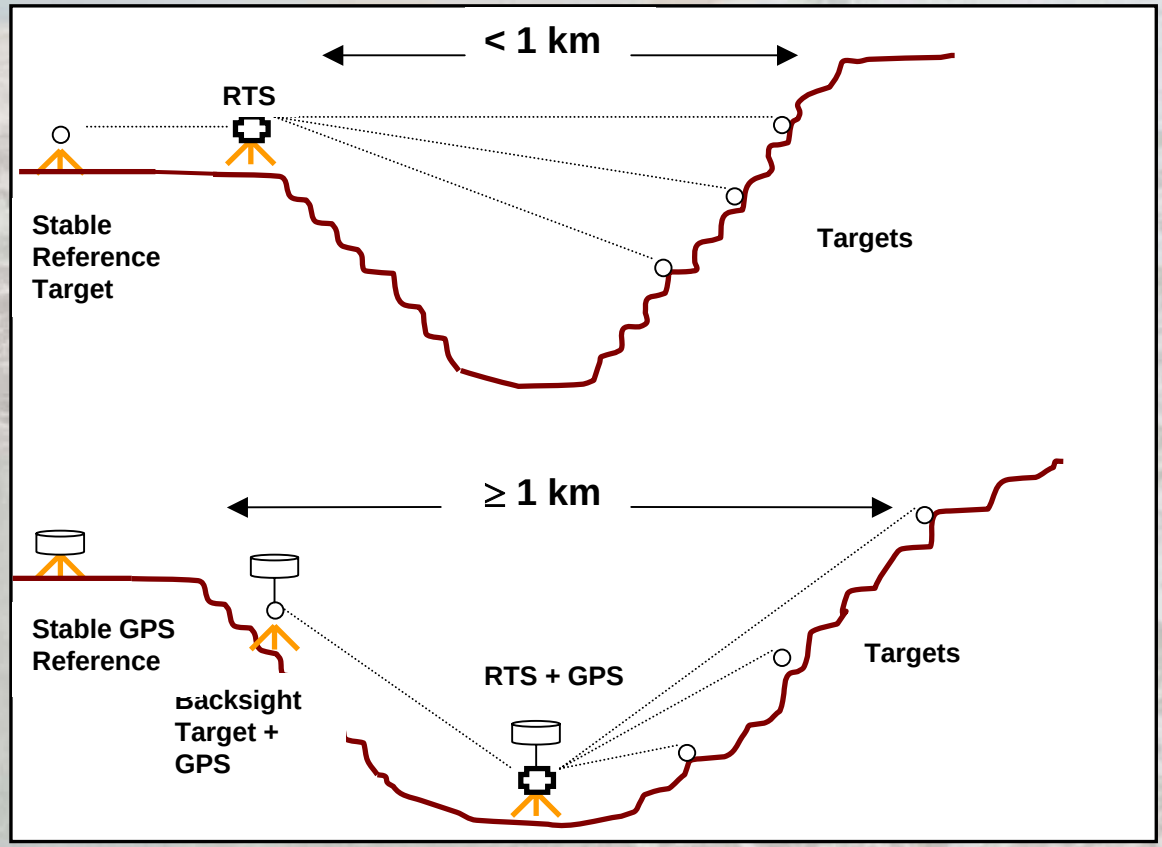
Use of DDS in large open pit mines

Chuquicamata copper mine in Northern Chile

the second largest in the world open pit mine (1000 m deep)

Network of 8 RTSs

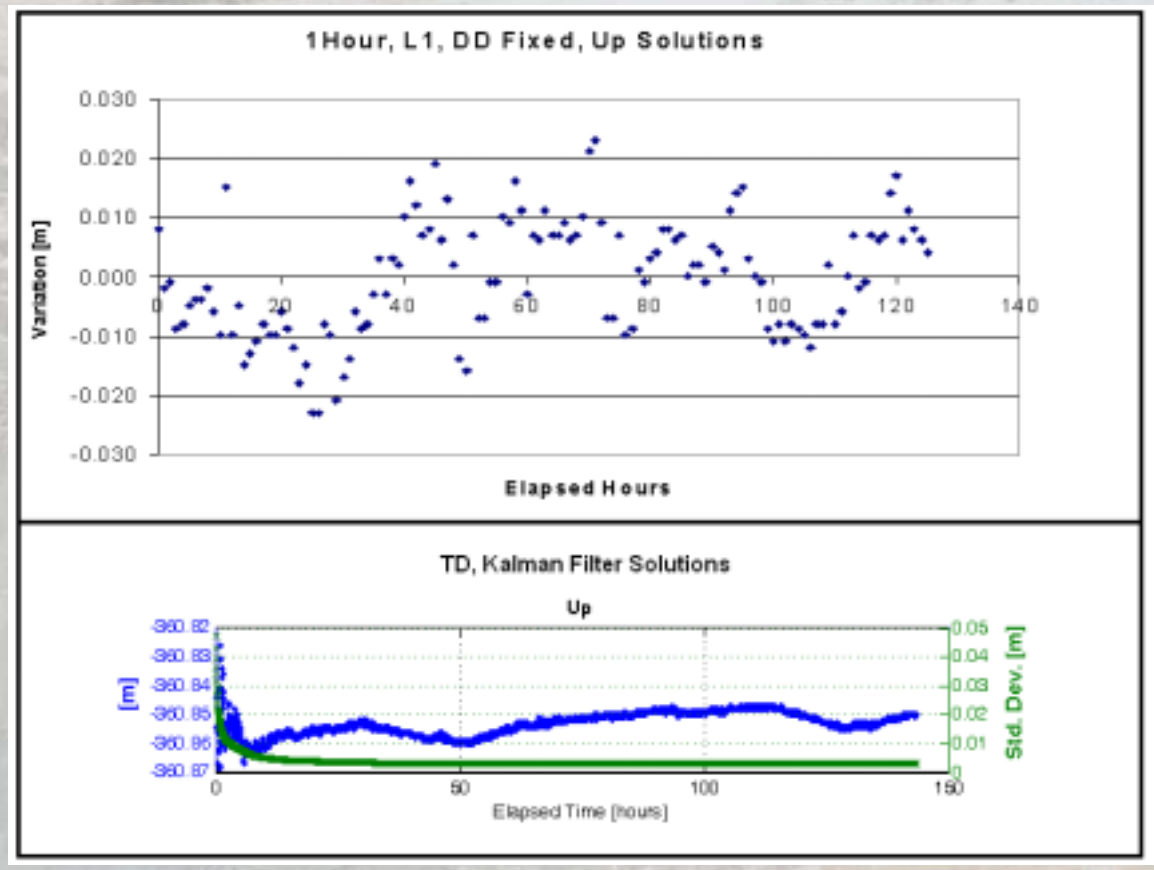
Use of hybrid RTS/GPS



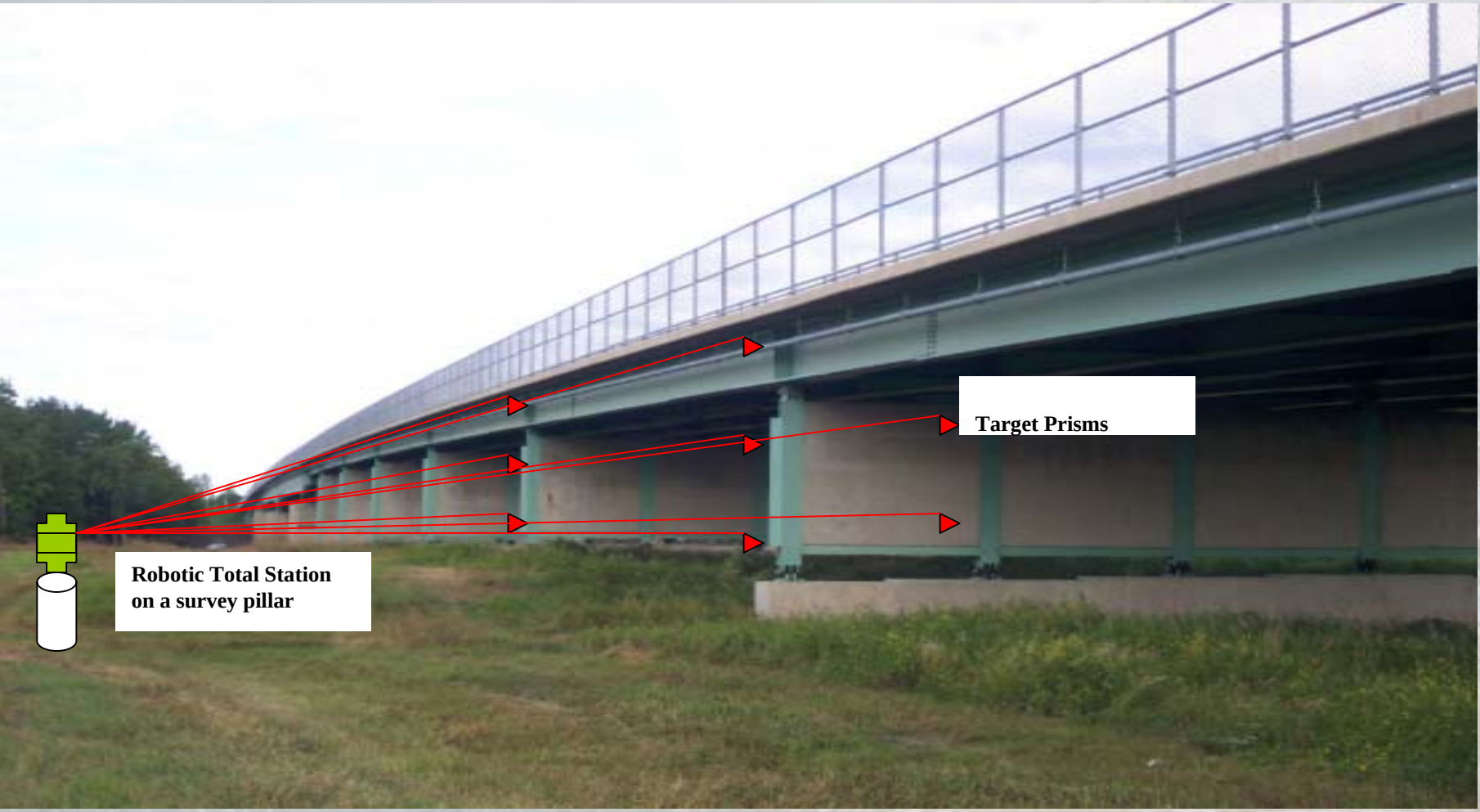
PPMS – Precise Position Monitoring System using GPS + pseudolites

- Software for fully automated deformation monitoring in harsh environment conditions
- Utilizes a delayed-state Kalman filter to process GPS triple-differenced carrier phases
- Capable of detecting millimetre level displacements without having to solve for ambiguity terms
- Not susceptible to false alarms caused by cycle slips
- Includes automated processing of signals from pseudo-satellites

Comparison of GPS processing using commercial and PPMS softwares



Portable DDS for structural monitoring



SCAN-DDS System
(reflectorless total station)
monitoring of oil tanks in Venezuela

Design of monitoring schemes

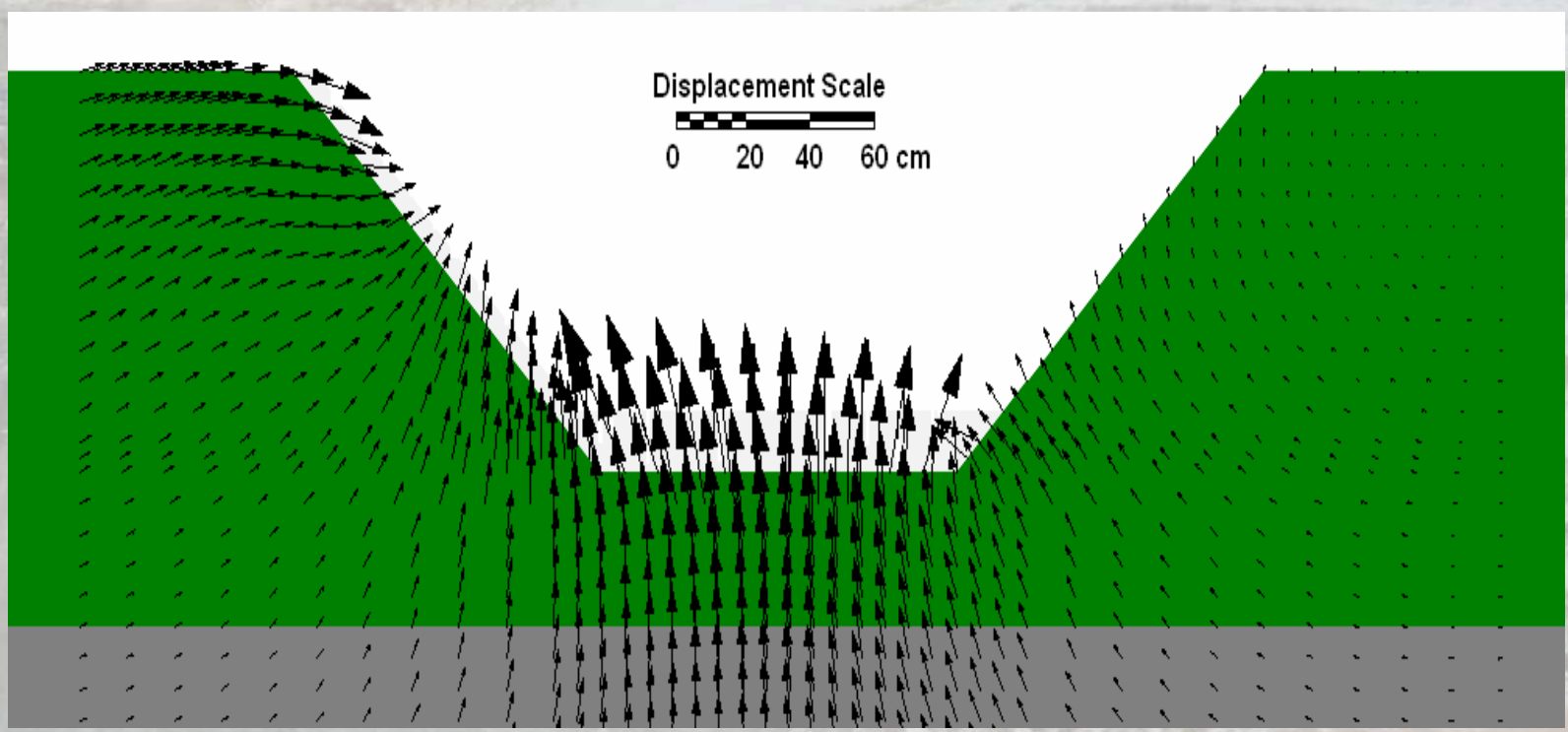
- Design of the monitoring scheme requires decisions to be made regarding the type, location, density, and accuracy of monitoring sensors.
- Location of the sensors or the observed targets must include points where maximum or critical deformations are expected
- Selection of stable reference points

Use of deterministic modeling in the design of monitoring schemes

A new method has been developed at CCGE based on deterministic (prediction) modeling of expected deformations using finite element method (FEM)

Deterministic model is developed from known properties of the material, known causative factors (loads), and physical relationship between stress and strain according to the laws of continuum mechanics

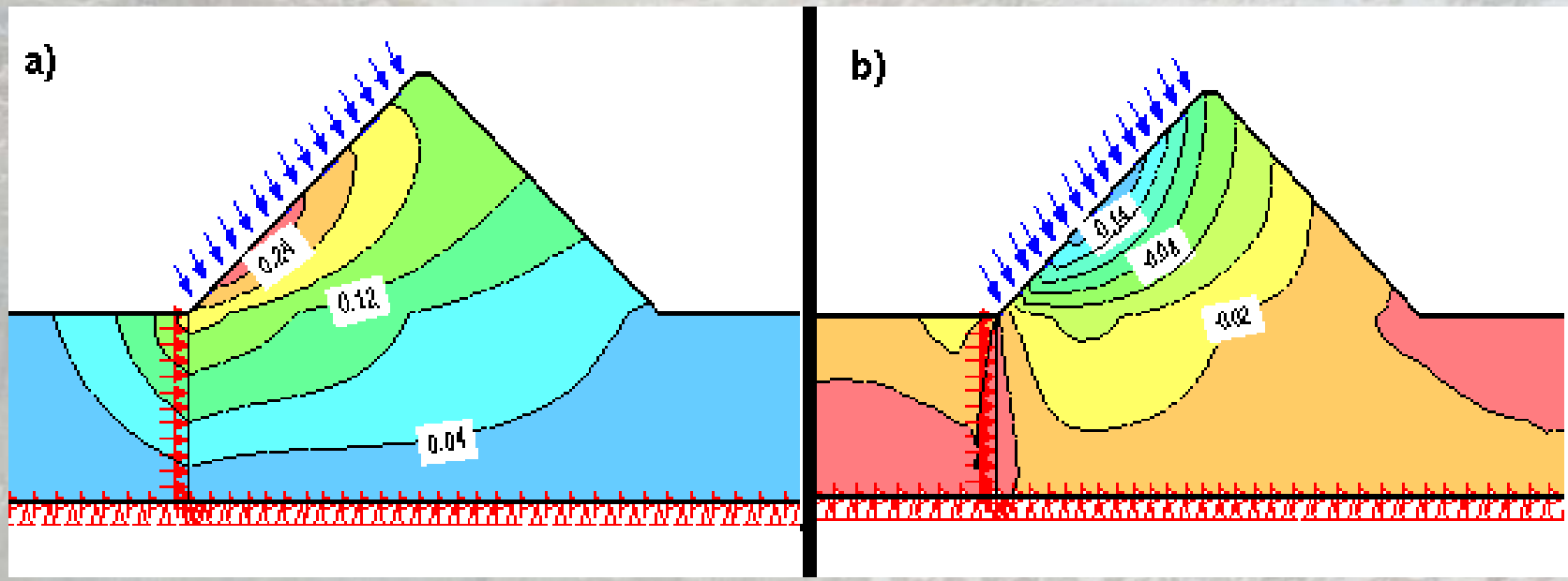
Predicted displacements due to mining activity



Isolines of predicted (modeled) displacements at a large CFR Dam

a) Horizontal displacements

b) vertical displacements



Integrated Analysis of Deformations

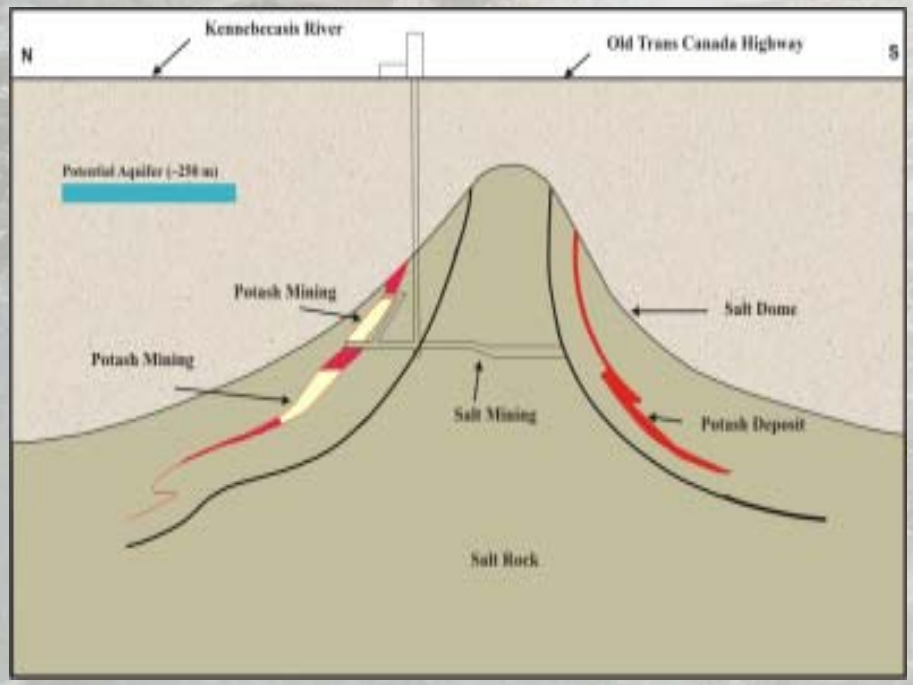
- **Geometrical analysis – determination of change in shape and dimensions + rigid body movements (UNB Generalized Method of Deformation Analysis)**

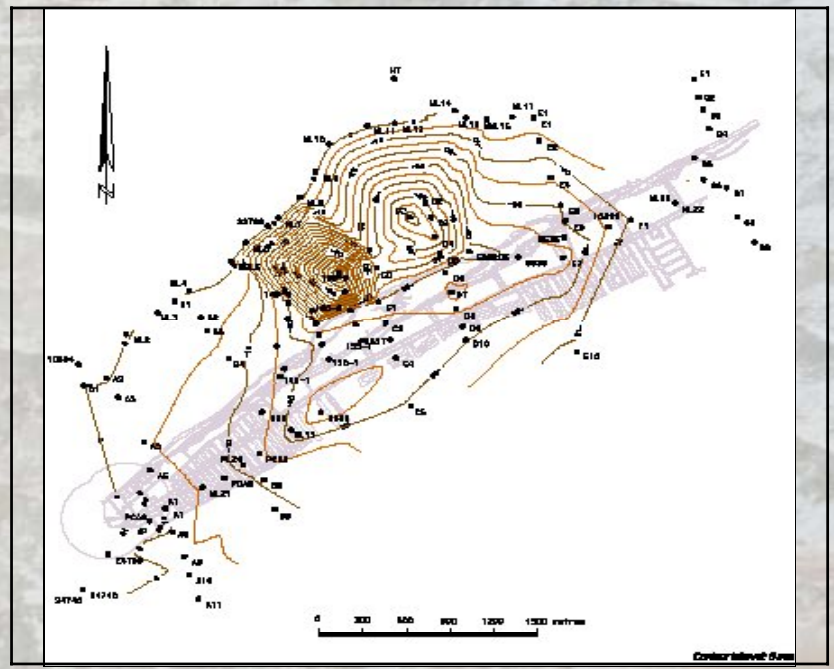
- **Deterministic (prediction) modeling of deformations using finite element method (FEM)**

By combining the geometrical model of deformations with the deformations obtained from the FEM model, one can determine the actual deformation mechanism and/or verify the designed geomechanical parameters

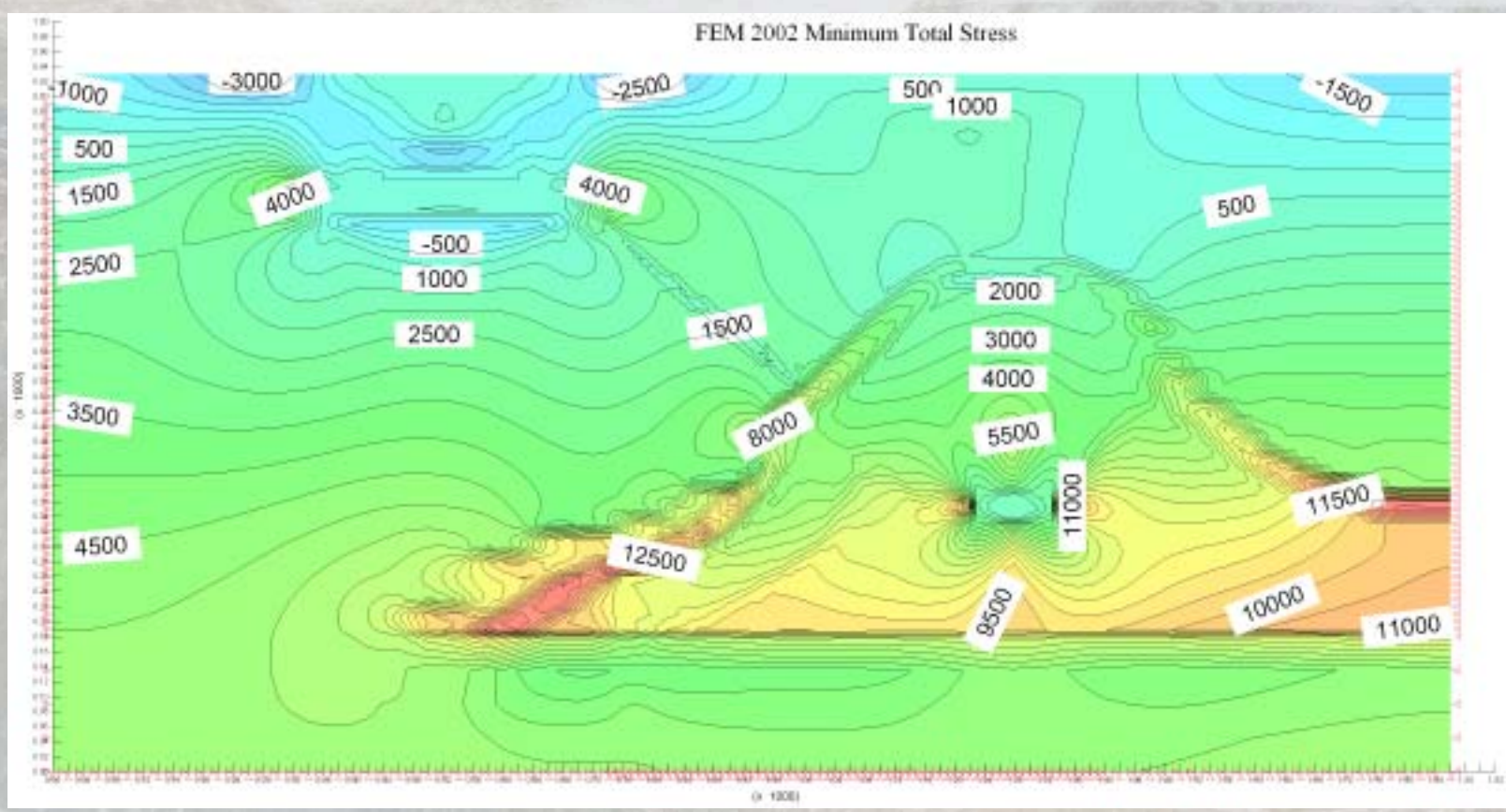
PCS Potash Mine N.B., Canada

Monitoring of Ground Movements since 1989
Modeling and Predicting Ground Subsidence using FEM
Modeling of Subsidence due to Hydrological Changes using FEM





Minimum total stress



Conclusions

- **Significant progress has been made in the development of fully automated monitoring systems and in the deterministic design and analysis of deformation surveys.**
- **Further research must be devoted to the development of cost effective and reliable monitoring systems utilizing the emerging new technologies such as MEMS**
- **Deterministic modeling of deformations should become a common tool in designing and interpreting monitoring surveys.**