# Combined GPS and EDM monitoring on Turtle Mountain, Alberta

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ABSTRACT
In 1903 a large rockslide, known as the Frank Slide, dropped some thirty million cubic meters of rock into the Crowsnest valley, burying part of the town of Frank, and killing approximately 70 people. A five million cubic meter portion of the mountain peak was left standing by the 1903 slide, and is considered unstable. In response to the hazard posed by this large unstable rock mass, the Alberta Government commissioned the development and installation of a real-time monitoring system for the mountain. The system is comprised of various subsystems with different purposes. Two subsystems will be discussed here. The first is a real-time deformation monitoring system based on the Global Positioning System (GPS). The second is a robotic electronic distance measuring (EDM) system. The GPS monitoring system designed for Turtle Mountain is a real-time system that uses low-cost hardware, carefully implemented, to achieve high accuracy results. It is deployed on various parts of the mountain that are of interest in understanding the overall movement of the rock mass. The EDM system supplements the GPS system by taking measurements on areas of the mountain where GPS measurements are impossible, such as the various cliff faces left by the original slide. This paper presents the development, testing, installation, and preliminary results of both of these two subsystems.

RÉSUMÉ
En 1903 une grande chute de rocher, connu sous le nom de “The Frank Slide”, a laissée tomber environ trente millions de mètres cubes de roche dans la vallée de Crowsnest, enterrant une partie de la ville de Frank et tuant approximativement 70 personnes. Une partie de la crête (pic) de montagne, mesurant cinq millions de mètre cube, reste intacte auprès de la glissière de 1903, et est considérée comme instable. En réponse au risque pose par cette grande masse instable de roche, le gouvernement d’Alberta a commissionné le développement et l’installation d’un système de surveillance en temps réel pour la montagne. Le système est composé de divers sous-systèmes avec différents buts. Deux de ces sous-systèmes seront discutés ici. Le premier est un système en temps réel de contrôle de déformation, basé sur le système de positionnement global (GPS). Le seconde est un système de mesure de distance éléctonique robotique (EDM). Le système de surveillance de GPS conçu pour Turtle Mountain est un système en temps réel qui utilise du materiel peu coûteux, soigneusement mis en application, pour atteindre des résultats de precision très élévés. Il est déployé sur des diverses parties de la montagne qui sont d’intérêt pour la comprehension du mouvement globale de la masse du rocher. Le système d’EDM est un complément du système GPS, prenant les mésures des régions de la montagne où les mésures GPS sont impossible, tels les diverses falaises restant de la chute de rocher originale. Cet article présente le développement, l’essai, l’installation et les résultats préliminaries de ces deux sous-systèmes.

## 1 INTRODUCTION

In response to the risk of a rock avalanche from the South Peak of Turtle Mountain (Figure 1) a near real-time deformation monitoring system was commissioned by the government of Alberta and installed by a group of consultants, researchers and government departments (Moreno and Froese, 2006). Two components of this system are a network of Global Positioning System (GPS) receivers and an electronic distance measuring (EDM) system. The GPS system is based on single frequency GPS equipment which has allowed costs to be kept low since the GPS equipment is at risk due to rockfall, extreme weather, and vandalism. The EDM system is based on a robotic total station that takes its measurements from a municipal pumphouse across the valley.

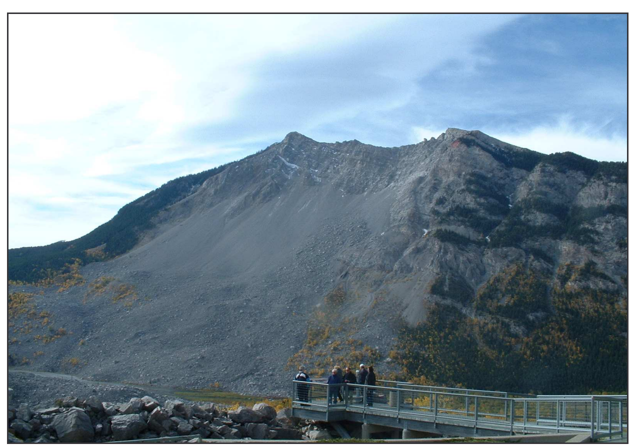

*Figure 1. View of Turtle Mountain taken from the northeast. The prominent peak to the left (south) of the Frank Slide scar is South Peak.*

## 2 GPS SYSTEM

The harsh environment found on Turtle Mountain made the design of the GPS system quite challenging. The GPS receivers could expect to encounter severe weather (including frequent electrical storms), vandalism, power shortages, and even rock falls that threatened to undermine the stations. As such, it was decided to custom design a robust GPS receiver that used solar power, wireless communications, and whose cost was low enough to be considered potentially disposable.

In order for the data from the GPS system to be usable for both early warning of a potential event and for analysis of small / slow movements, data is processed in two ways. First, for rapid detection of events, a kinematic solution is processed using 1Hz GPS data. Second, for more precise measurement of deformation, static GPS solutions are processed using one hour blocks of raw 1Hz GPS data. Most of the evaluation on the quality of the system has been done using the static data sets as the kinematic data, to date, has not shown any change in coordinates that is outside the error budget.

*Figure 2. Typical Turtle Mountain GPS Station showing the antenna (right), battery (centre) and solar panel (left)*

### 2.1 GPS System Design

The GPS system designed for Turtle Mountain is based on single frequency GPS boards from Novatel Inc of Calgary AB. Single frequency receivers are available at a much lower cost than dual frequency equipment and are capable of providing high accuracy results provided that short baselines are measured (as is the case on Turtle Mountain). Both Novatel SuperStar II and Novatel OEMV-1 GPS boards have been used with great success on this project.

Data from the GPS satellites is collected by the GPS boards in the custom units and then transmitted through standard 802.11 wireless links to an internet connection where it is forwarded to a central processing server in Vancouver. Once the data has arrived in Vancouver it is processed and archived for analysis and interpretation. The following figure (Figure 3) shows the flow of data from the GPS satellites to the processing server.

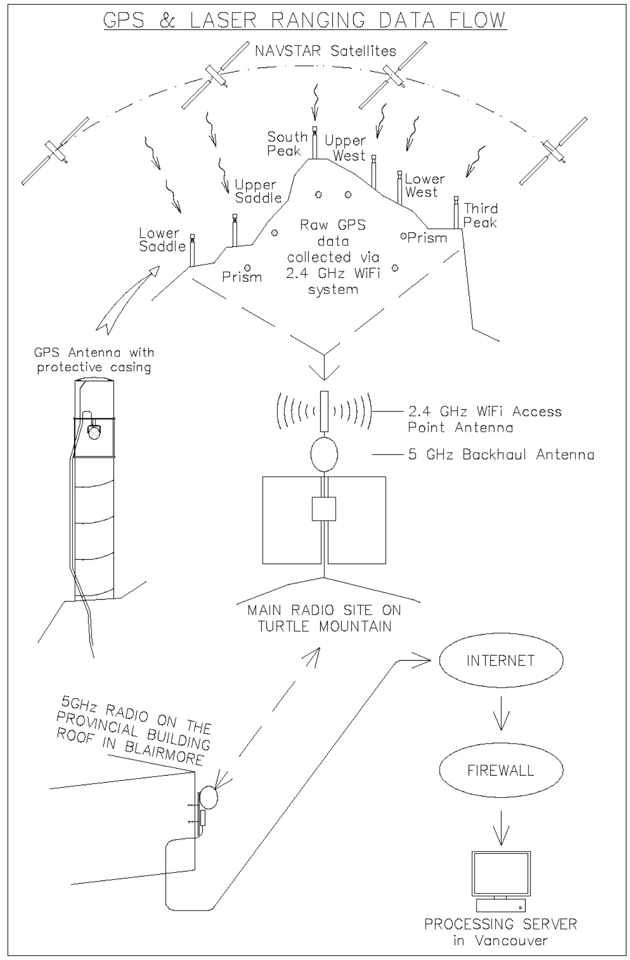


*Figure 3. Data Flow Chart*

The network of GPS units has been deployed so that there is one station on a relatively stable portion of the mountain (3rd Peak) and the rest of the GPS units are placed in areas that are expected to have higher rates of movement. The 3rd peak GPS station is used as the base station when processing the GPS data in order to minimize the baseline lengths and thus improve the quality of the GPS results. This methodology results in baselines that are less than 400m in length.

As it is not certain that 3rd Peak is stable an additional base station has been installed in the valley below the mountain (co-located with the EDM installation.) This second base station is approximately 3000m (1000m vertical and 2825m horizontal) away from the mountain peak. Due to the large distance from the alternate base station to the mountain, data is processed between it and the 3rd Peak station with large blocks of static data and then analyzed on a weekly basis rather than hourly. We have found that this method yields results with a horizontal accuracy of 3-4mm which, over time, is sufficient to prove that 3rd Peak remains stable. The vertical accuracy from this baseline has been 2-3 times worse than the horizontal and, as such, requires additional filtering to prove the stability of 3rd Peak in the vertical direction.

2.2 GPS System Preliminary Results

The GPS system has functioned on Turtle Mountain for approximately one year. During that time a significant amount of GPS data has been collected, processed and analyzed. The following graphs (Figures 5, 6, 7, 9, 10, 11) show the results that were observed during 2007 for two of the GPS stations known as South Peak and Upper West. These graphs show the deviation from the mean of the raw static results as well as a 12 hour moving average for the same. The raw data is shown in a blue colour and the 12 hour moving average is shown as a black line on the graphs. These results have not been filtered or adjusted except for the addition of the 12 hour moving average.

The first set of three graphs (Figures 5, 6 and 7) shows the results from the South Peak station. As its name infers this GPS station is set on the South Peak of Turtle Mountain. This is a significant installation as South Peak is the primary area of the mountain which is under study and considered potentially unstable.

Figure 4. South Peak GPS Station

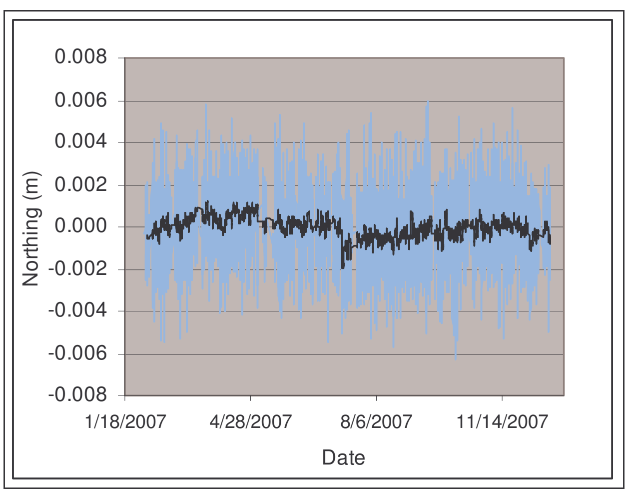


Figure 5. South Peak Northing Results

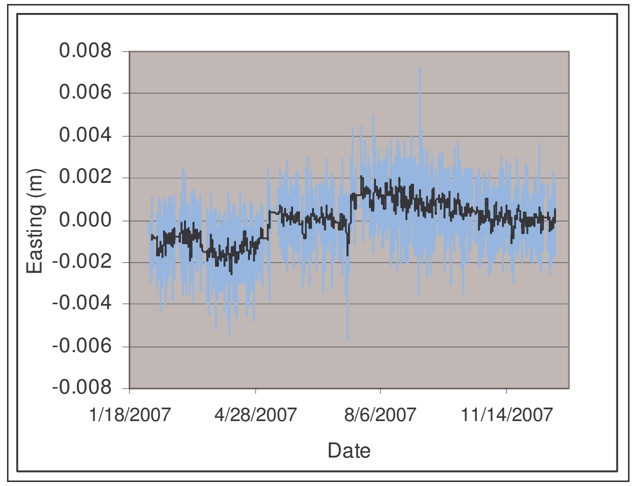


Figure 6. South Peak Easting Results

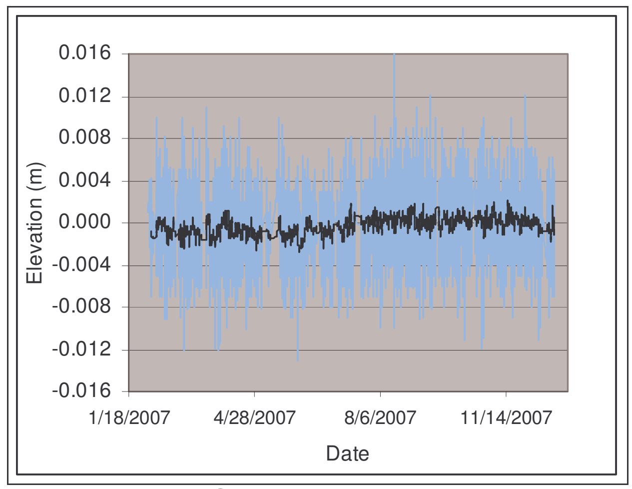


Figure 7. South Peak Elevation Results

The results from the South Peak station (Figures 5, 6 and 7) suggest that the accuracy of the raw GPS results is typically within 4-6mm for the horizontal coordinate components and within 8-12mm for the height. This difference between the horizontal and vertical accuracies is typical with any GPS measurements due to the geometry of the satellite constellation with respect to the GPS unit's antenna. The vertical results will always be weaker than the horizontal. Most often the errors in the vertical will be found to be 1.5 to 2 times more significant than those found with the horizontal.

The results shown here are not able to conclusively identify any movement of the South Peak station during the monitoring period. There are some trends in the North – South direction that could possibly be slight movements, however, the change in coordinates is not significant enough to be considered outside of the error range for the measurements and additional years of monitoring will likely required to verify the movement patterns.

The Upper West GPS station is on the West side of the South Peak adjacent to one of the deep fractures that encircles the peak (Figure 8). Upper West and Lower West have been installed on opposing sides of a large crack which is also being monitored with surface extensometers (Moreno and Froese, 2006).

The accuracy of the measurements (Figures 9, 10 and 11) at the Upper West station is consistent with the accuracy observed above at the South Peak station. The Easting component of the coordinate has shown change of approximately 3-4mm over the course of the year (Figure 10). This coordinate change seems to be directly related to the annual freeze / thaw cycle, which is consistent with the results observed on other sensors on the mountain (Moreno and Froese, 2007). This is suspected because the start of the movements tends to correspond very closely with the times when the air temperature rises or falls below the freezing mark, leading to either changing thermal gradients in the rock or freezing and expansion of water in the cracks around the peak. (This has been visible in previous data sets as well.) The dates where the thawing and subsequent freezing of the rock occurred are shown as red and blue vertical lines respectively on the Easting graph.

*Figure 8. Upper West GPS Station (Lower West Behind)*

The preliminary results from the GPS system on Turtle Mountain have indicated that the system is capable of detecting movements of 2mm given 12 hours of measurements, movements of 12mm given one hour of measurements, and movements of more than a few centimetres given one second of data. These data used to generate these results was collected over a long time period with varying environmental factors.

The GPS conditions on Turtle Mountain are nearly ideal. Future testing will include areas with less ideal conditions as well as areas that require measurement of longer baselines. The GPS measurements being made between the 3rd Peak GPS station and the alternate base station at the total station installation indicate that the accuracy of the measurements does deteriorate fairly quickly with baseline length. However, for any study area where short GPS baselines are possible this is proving to be a powerful technology for deformation monitoring purposes.

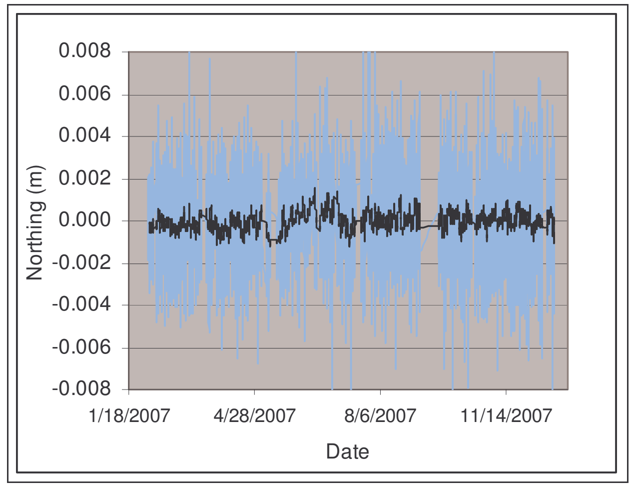


*Figure 9. Upper West Northing Results*

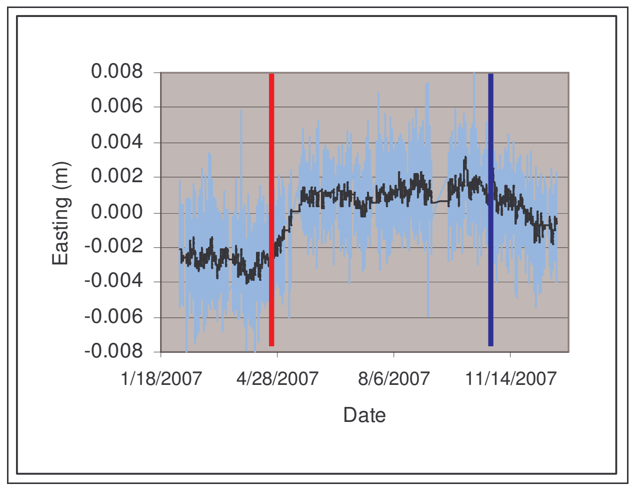


*Figure 10. Upper West Easting Results*

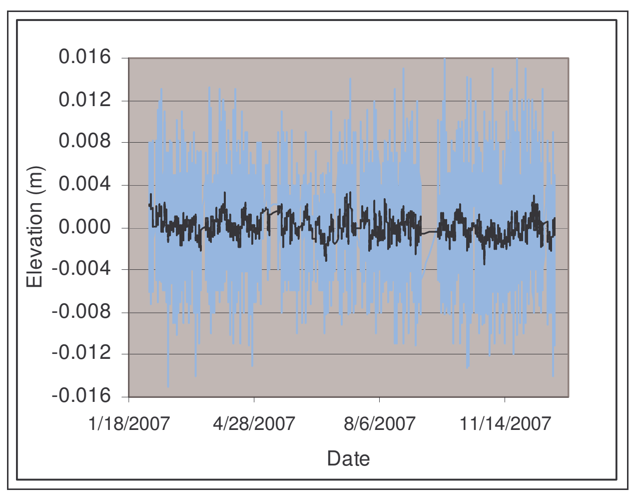


*Figure 11. Upper West Elevation Results*

## 3 EDM SYSTEM

There are several areas on Turtle Mountain where the installation of GPS receivers or other active sensors would be impractical or even impossible due to the steep and unstable nature of the eastern face of the mountain. In order to realize some useful monitoring data for these areas corner cube reflectors (prisms) were installed. At present there are 20 prisms installed on the mountain that allow for the measurement of distances from a total station installation in the valley at the base of the mountain (total distances ranging between 2150m and 2965m). These prisms are primarily mounted on the rock face left by the original 1903 slide, but some prisms have also been placed on undisturbed portions of the mountain for reference.

*Figure 12. Vertical Systems International Installing Prisms below South Peak*

Ideally, for deformation monitoring, a total station would be used to measure both angles and distances to prisms yielding a three dimensional coordinate for analysis. In the case of Turtle Mountain, the distance between the mountain peak and a location suitable for placement of a total station was simply too far for angular measurements to produce a meaningful result. (Even high quality precision total stations are subject to errors of several centimetres in angular measurements at such a long distance.) However, we are able to measure distances with good accuracy at long distances and so a robotic total station was installed to perform automated distance measurements.

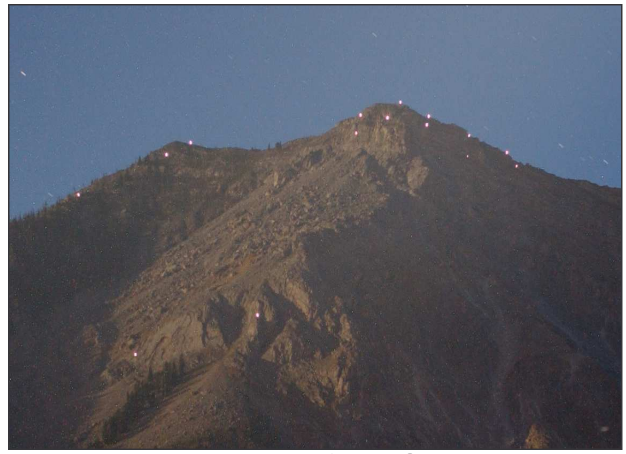

*Figure 13. Night View of Peak Showing Prisms Reflecting Light from a Spotlight*

### 3.1 EDM System Measurement Corrections

The accuracy of electronic distance measurements is quite dependant on the characteristics of the atmosphere between the device making the measurements and the prism being measured. Errors can be in the magnitude of several centimetres at long distances when temperature, humidity, and pressure are not properly compensated for. The normal procedure would be to measure these environmental variables, compute a correction factor, and apply it to the measured distances. In the case of the Turtle Mountain project this was not practical as the prisms are approximately 3000m away from the Total Station. This large distance would require multiple measurements of atmospheric conditions along the path of the measurements in areas that are in-accessible. Due to these problems we decided on an alternate methodology to correct the measurements.

Four of the prisms along the ridge are co-located with GPS monitoring stations; therefore, at any given point in time, the coordinates of these points are 'known' (based on the current GPS measurements). Rather than using atmospheric measurements to correct our electronics distances it was decided to co-locate a GPS unit with the total station which would give us four GPS baselines that would be common with measured distances. We are then able to determine a correction scale factor between the electronic distance and the GPS distance which can be applied to other distances measured at the same time. It is assumed that for a given instant in time the atmospheric conditions between the total station and a prism 'n' would be very similar to those between the total station and a prism 'n+1', which is in the same area.

This methodology has proven effective when all of the 4 baseline prisms are measured; however, there are often times when clouds, fog, snow, etc make measurements to some of the prisms impossible. This becomes particularly troublesome during the winter months. Since all of the measurements are dependant on the baseline prisms no measurements can be made unless they are clear for measurements.

Figure 14. View of Turtle Mountain from the Total Station Enclosure

### 3.2 EDM System Preliminary Results

To date the EDM measurements are being made at 15 minute intervals to all 20 of the prisms. The data is transmitted in real-time to the same processing server used by the GPS system for archiving and analysis. The following graphs show a sample of the results that have been achieved to date for one of the prisms.

The results from the EDM system have much more noise inherent in the measurements than those from the GPS system. This is most likely due to variations in the atmosphere between the total station and the prisms on the mountain during the measurements. The results for two of the prisms on South Peak are shown below on Figures 15 and 16.

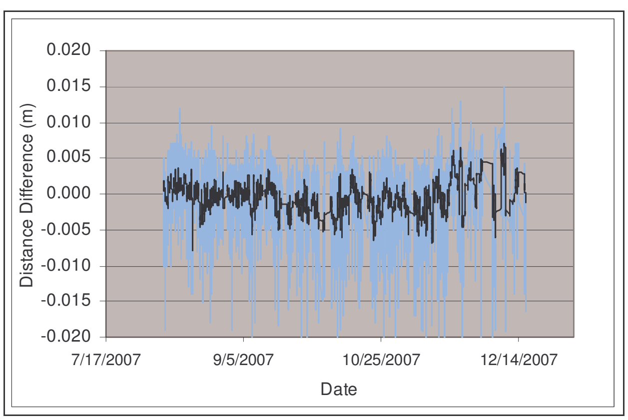


Figure 15. Displacement results for Prism 4 from August 2007 to December 2007

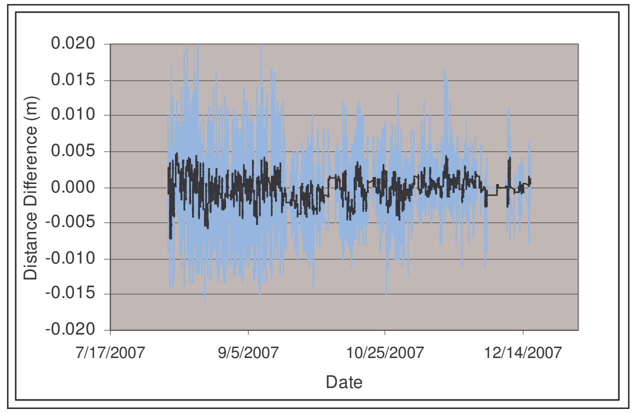


Figure 16. Displacement results for Prism 11 from August 2007 to December 2007

These graphs show approximately four months of EDM data from Turtle Mountain. The blue lines show the difference between the raw measured distance and the mean of all distances. The black lines show a 96 point moving average (24hr moving average) of the raw differences. The accuracy of the measurements with 24 hours of data appears to be within ±8mm; however, the raw measurements have shown errors of several centimetres in some cases.

Figure 17. Total Station Enclosure Showing Concrete Support Column

## 4 CONCLUSIONS

A subset of the initial year of data from the Turtle Mountain GPS and EDM systems is presented. These systems are installed as part of the combined deformation monitoring network on the South Peak of Turtle Mountain. Based on the measurements obtained to date it appears that movements of 2-3 millimetres can be detected by the network of GPS stations and movements of 5-8 millimetres can be detected by the EDM system. These consistent results have given confidence as to the level of precision and repeatability with which the monitoring stations can resolve very small displacements on the mountain. The GPS system will be supplemented with an additional six GPS stations in the summer of 2008. The results obtained from these and other stations will be available in the future via the Alberta Geological Survey's website at ags.gov.ab.ca.

## ACKNOWLEDGEMENTS

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