IS PARLIAMENT HILL MOVING?

BY SÀNDOR VÀMOSI AND MARIO BÉRUBÉ

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The Geodetic Survey of Canada, which specializes in the precise measurements needed for high-precision surveys, was asked to measure the rate and magnitude of ground movement.

THE PARLIAMENT Buildings in Ottawa stand close to the edge of a high bluff that rises above the south shore of the Ottawa River. Some buildings are a mere 20m from where the cliff falls abruptly to the river 50m below.

In 1981, engineers noticed that the ground was sinking between the buildings and the cliff edge and that remedial action might be needed to stabilize the cliff face.

Scientists from the Geodetic Survey established a series of "control stations" from which they could make measurements to selected points on the cliff face. They could then ascertain movement, if any, by repeating the sets of measurements at regular intervals and comparing the results.

Reconnaissance and Monumentation

For the control stations, engineers selected sites that would afford a good view of the cliff face. They chose locations at Nepean Point, at the rear of the Supreme Court building and on the north, or Hull, side of the river. These control stations constituted a network from which measurements would be made to monitoring points on the cliff face (Fig. 1).

Before constructing the observing piers, they examined the terrain surrounding the project area to determine if any of the proposed sites might be unstable. There was some concern, for example, because a large-scale map of the area prepared in 1876 (Fig. 2), showed that the river bed had changed and that a landfill site had been created on the north side of the river.

Other constraints also limited the choice of sites for the observing piers: construction of the Museum of Civilization on the north side of the river, excavation for the foundation of the National Art Gallery at Nepean Point, and National Capital Commission specifications about where monuments could and could not be constructed.

Construction of the monuments began in December 1983. For each observing pier on the Hull side of the river, builders placed a large concrete block as foundation below the frost line and backfilled with about 10m^3 of granular material to minimize seasonal movement. Piers were constructed with forced centring cylinders or five-eighths-inch threaded centring plates, suitable for a base plate.

The monitoring stations on the cliff face were designed to accept pedestal-type forced centring to accommodate reflector prisms. Most stations were set at least one metre into the rock face and cemented to ensure stability (Fig. 3). Monitoring stations at the top of the inclinometer boreholes, established by NRC to measure changes in incline, were designed differently, but forced centring was also used for the prisms.

Distance measurements

In the summer of 1984, surveyors began measuring distances using a KERN Mekometer ME3000 (Fig. 4), a high-precision electronic distance measuring (EDM) instrument with a range of about 2km. The ME3000 was chosen as the most suitable single wavelength instrument for accurate measurement of small surface displacements.

Before and after each set of measurements, the instrument was calibrated at the Geodetic Survey electronics laboratory for frequency and at the National Geodetic Base Line at Shirleys Bay for scale and additive constant.

The precision of distance measurements with EDM is largely limited by uncertainties in determining the average air temperature along the line being measured. Simultaneous meterological readings were taken at both ends of the lines to minimize the effects of atmospheric variations induced by the large water surface across which most measurements were made. With the special conditions that exist in this trilateral network, the estimated precision of the measurement is $\pm$ 0.5mm + 2.5 parts per million of the line length.

Surveyors could measure only in early spring and late fall when the view was not obscured by foliage. Some distances, however, were measured to nine of the monitor stations in June 1984 and in August a new control station was established at Majors Hill Park to monitor the east side of the cliff. The first measurements were not made to the five inclinometer stations until late September and early October (Fig. 5).

Measured distances ranged in length from 37m to 944m. The first complete set of measurements of the network, made in the fall of 1984, was used as a basis for comparison with the 1985 and subsequent measurements.

Measurements were made at two differnt times of year. Each epoch, or group of distance observations, was adjusted separately to obtain the positions of the monitoring points on the cliff face and compared with previous results to determine apparent movements.

At each epoch of measurement, surveyors determined the heights of the stations by special order leveling (Fig. 6). The data when analyzed indicated that no significant vertical displacement of any monitoring point had occurred. The heights were nevertheless necessary to compute precise slope distances used in analysis and computation of horizontal coordinates.

Network Adjustment and Analysis

After the distances were corrected for meteorological and instrumental effects, they were adjusted using a computer-based three-dimensional adjustment program called CASPER.

A minimum constraint adjustment was performed to analyze the consistency of the observations and to detect possible blunders. Although the EDM instrument was calibrated before and after each observation session, adjustments were performed to ensure that no significant instrumental errors were present in the measurements.

The resulting planimetric coordinates and the variance-covariance matrix of each adjusted group provided the information necessary for movement analysis. Coordinate differences between measuring epochs were compared to 95 percent statistical confidence regions, or ellipses, derived from the variance-covariance matrix computed for the coordinates. The size, shape and orientation of the 95 percent confidence ellipses depended on the estimated standard deviations of the measured distances and on the geometrical configuration of the observed network.

Vectors representing the coordinate differences between measuring epochs were plotted with the 95 percent confidence ellipses on a network diagram, and examined for systematic trends. The confidence ellipses were examined to detect weaknesses in the network. Vector and confidence ellipse diagrams were also plotted for each point.

Interpretation of Results

The vector-confidence ellipse diagrams (Fig.7) were interpreted as follows:

— If the coordinate difference vector fell within the 95 percent confidence ellipse, then physical displacement of the point was considered to be insignificant.

— If the coordinate difference vector extended beyond the limits of the corresponding 95 percent confidence ellipse, then physical displacement was deemed to be significant.

Since the start of this project, Geodetic Survey has made measurements twice annually. With the exception of one point on the west cliff face where a displacement of about 5mm was detected, no significant movement of the monitoring points has occurred. Measuring will likely continue, however, until stability is assured.

Close look at the cliff face showing deterioration of the rock surface.

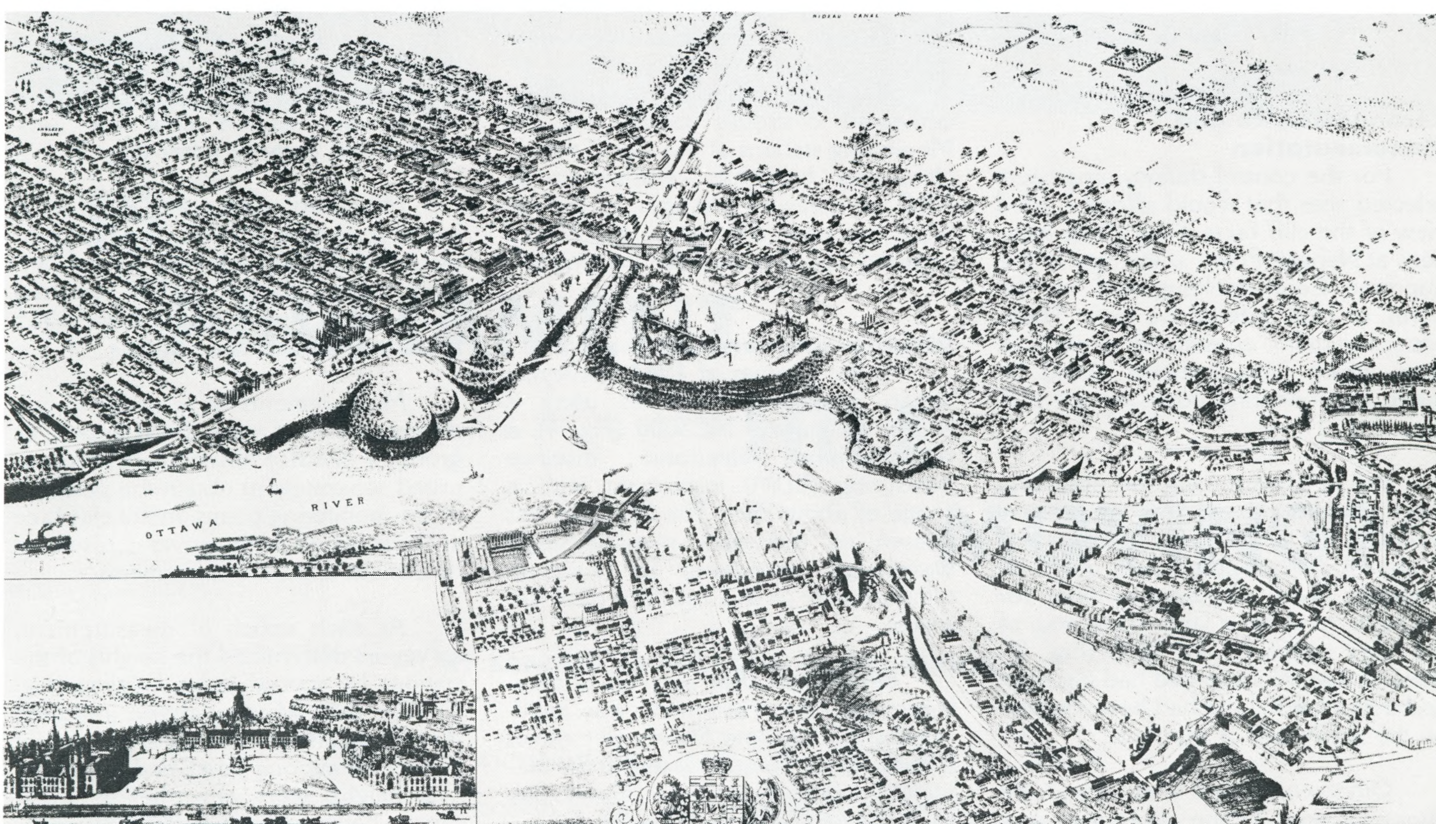

Figure 2. Bird's-eye view of the city of Ottawa in 1876.

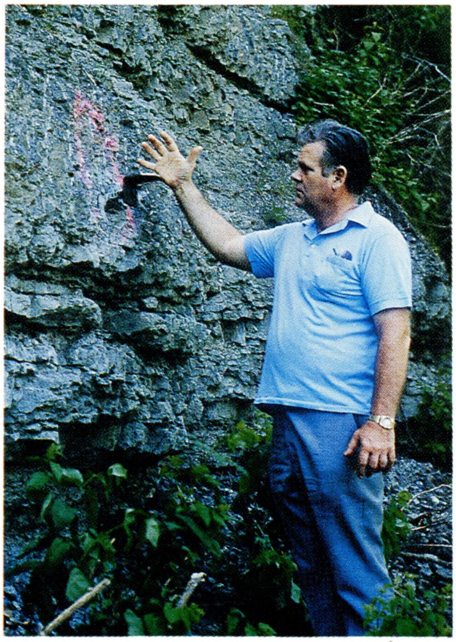

Figure 3. Auggie Puppa, project manager, shows a pedestal drilled into the cliff face to support a reflector used in electronic distance measurement.

Figure 4. ME 3000 instrument used to measure distances with submillimetre precision.

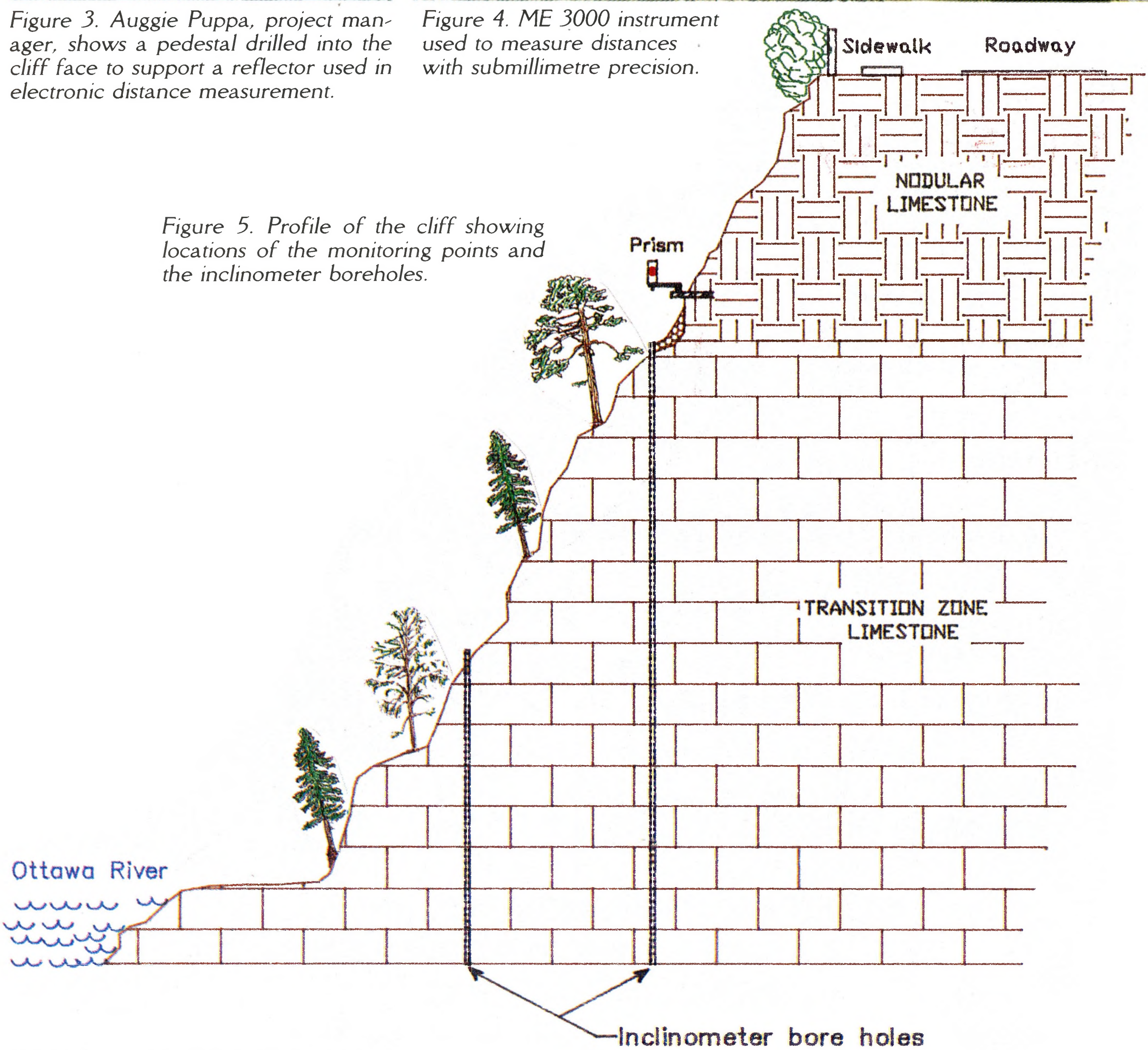

Figure 5. Profile of the cliff showing locations of the monitoring points and the inclinometer boreholes.

Figure 6. Precise geometric leveling was done to determine the heights of the control and monitoring stations.

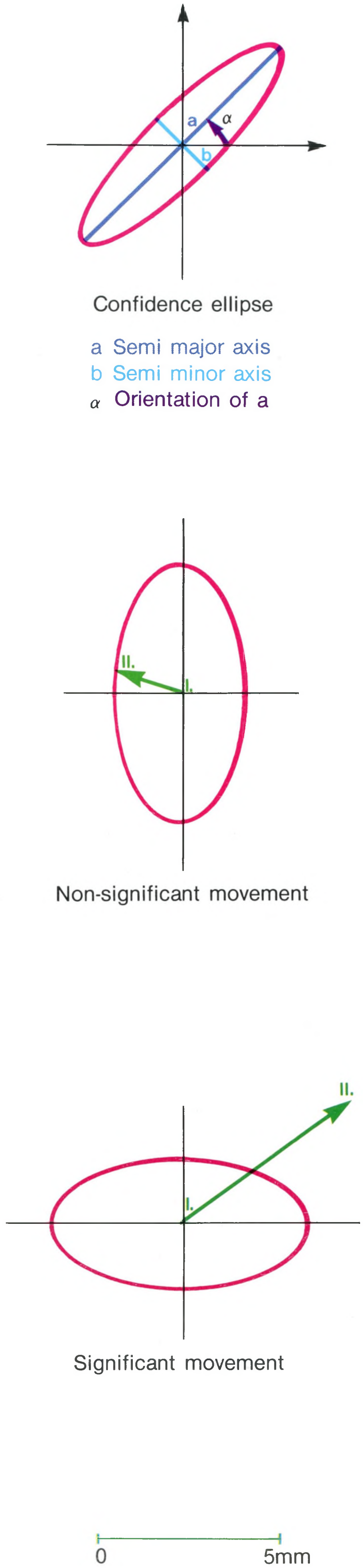

Figure 7. Confidence ellipse used to express the precision of the computed movements. Conclusions are based on the displacement vector and its confidence ellipse. If a change in coordinates is within the confidence area, the displacement is not considered significant. If the vector is outside the confidence area, significant movement has occurred at that station.

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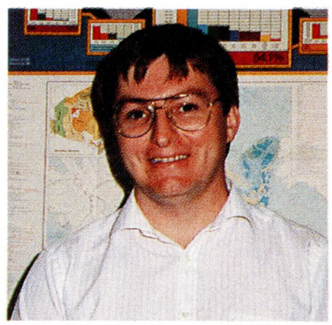

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