Instrumentation and performance of tied-back shotcrete shoring in sand adjacent to a hospital structure

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Abstract: Recent additions to the Brantford General Hospital expansion included construction of a new hospital wing, involving excavations of up to 11 metres (36 feet) depth, in loose to compact sand adjacent to an existing eight-storey hospital structure. The tendered contract called for interlocking caisson walls. An alternative, proposed by HC Matcon Ltd., was to use tied-back shotcrete shoring as the method of temporary excavation support. Due to a lack of familiarity with this method in the area, the uncertainty of attaining near-zero movements, and the proximity of adjacent 'lifeline' structures, the design-build team of HC Matcon and Isherwood Associates implemented a comprehensive program of quality control assurance.

The instrumentation for this program included inclinometers, standard and precision visual survey, electrolytic tilt-meters, and load cells. The inclinometers were generally placed directly behind the wall faces to ensure accurate monitoring of the shoring face and effects of installation procedures. Precision survey was used to monitor of the shoring and structural displacements. Electrolytic tilt-meters (electrolevels) were placed on the adjacent structures' foundation walls and floor beams to ensure an accurate differential movement history of the structure at critical points. Frequent data acquisition from the inclinometers and electrolevels provided timely feedback and permitted accurate assessment of the performance of the shoring system during installation. It allowed for rapid response by the design-build team to any unexpected movements of the shoring or adjacent structures.

Movements of the shotcrete shoring face in the hospital wing phase of the project were limited to 3 millimetres or 0.03% of the shoring height - equivalent to that achieved by caisson wall in similar ground conditions. Of note, the adjacent hospital structures' movements were measured as less than 3 millimetres, better than expected from a caisson wall system due to ground loss problems often associated with large diameter vertical and horizontal drilling. The excellent performance of the shotcrete shoring in the hospital wing phase was attributed to shoring design features, good workmanship, and rigorous quality control efforts by the design-build team. The monitoring results allowed for 'real time' reaction.

Introduction

At Brantford General Hospital (BGH) in Brantford, Ontario, an excavation up to 36 feet deep in a native, loose to compact, normally consolidated sand deposit was supported with tied-back shotcrete. Structures up to eight stories high were situated immediately adjacent to the excavation; see Fig. 1. For protection of the adjacent buildings, the design-build team set the goal of limiting shoring deflections to 6 millimetres.

To meet the movement control objectives, an approach involving soil face protection measures and a tieback stressing program was developed. A monitoring program, consisting of inclinometers, electrolevels, load cells, and standard and precision survey, was an integral part of the approach. Monitoring data indicated shoring wall movements were limited to a maximum of approximately 3 millimetres into-site, half the target limit. The excavation was completed on schedule, with savings of 20 percent over a conventional shoring solution.

The BGH site is located on a major sand deposit. The sand was described as usually fine, grading to fine to medium, with a moisture content of 1 to 9 percent. Grain size distribution curves for the soil are shown in Fig. 2. Standard penetration test (SPT) and dynamic cone penetration test (DCPT) results indicated the sand was loose to compact near the surface, becoming increasingly compact with depth, and are summarised in Table 1.

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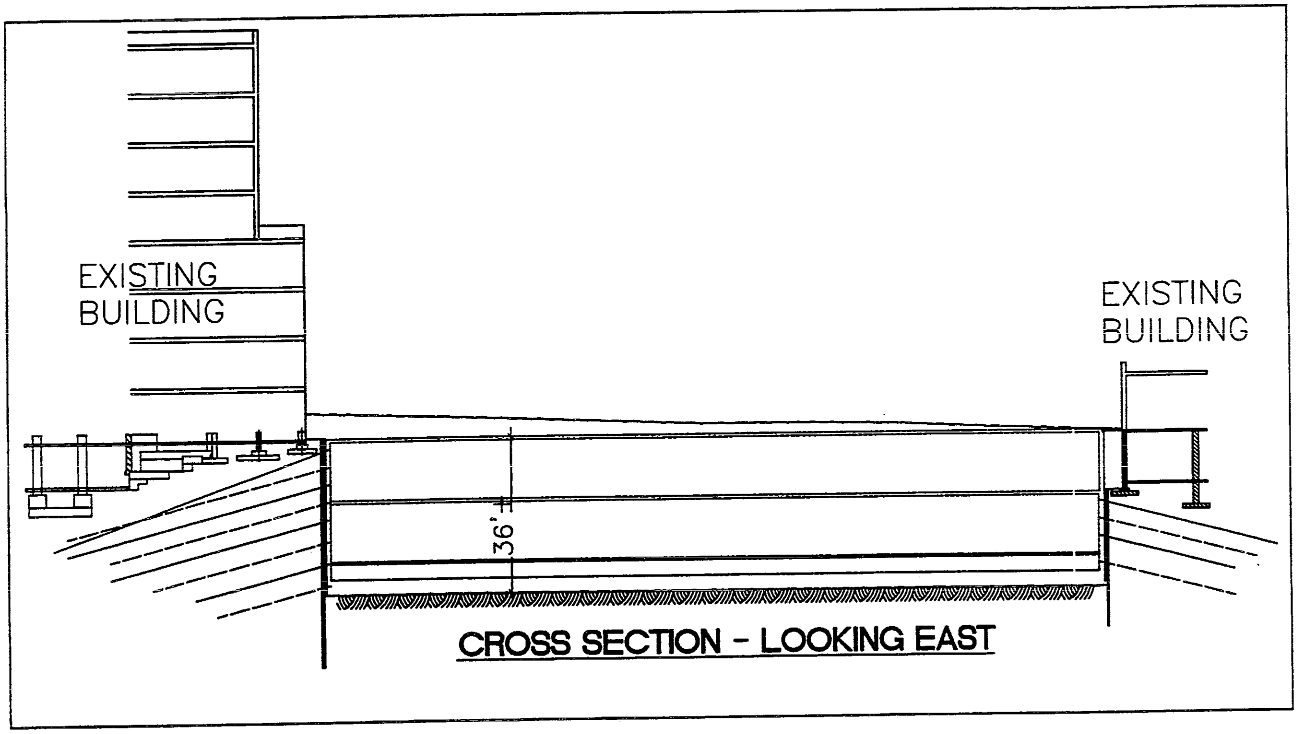
Fig 1. Cross Section of Site



Advantages of tied-back shotcrete shoring on the BGH project

- The impetus to use tied-back shotcrete shoring was potential cost savings, arising mainly from lower material costs, and economies related to the use of light construction equipment, site-deployed with relative ease.
- The compactness and versatility of the installation equipment associated with the method were ideal for coping with existing grades as steep as 3 horizontal to 1 vertical, and working in close proximity to adjacent buildings.
- Relatively low construction vibrations reduced the potential for settlement of adjacent hospital foundations supported on the sand deposit and disruption of hospital services, such as surgeries. Construction activities causing noticeable vibrations would have been halted by the hospital administration on a routine basis.
- Smaller equipment, lower concrete volumes, fewer compressors, and less truck traffic contributed to lower dust and pollution levels, a significant hazard in a hospital environment, particularly in facilities treating transplant patients or patients with respiratory difficulties.
- Small-diameter tieback installation through berms with self-drilling hollow bar meant negligible impact on the soil mass.
- Tied-back shotcrete walls were approximately 20 percent of the thickness of conventional shoring walls.
- Excavation to final grade was completed sooner, since it was carried out simultaneously with shoring construction allowing the general contractor to get a head start on foundation construction.
- Shoring modifications were relatively easy to effect due to the inherent flexibility of the method, for example, when the foundations of the adjacent BGH structures were found to be higher than contract drawings indicated.

Approach to movement control

Uncertainty existed regarding the level of deflection control that could be achieved using tied-back shotcrete in the type of soil on the BGH site. Lack of precedent and monitoring data was a source of concern to all parties. The design build team had responsibility for system performance and viewed proper handling of the non-cohesive, vibration-sensitive soil during shoring installation as a key challenge to limiting ground movements. The following measures were taken to

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Fig 2. Grain Size Distribution Chart [1]

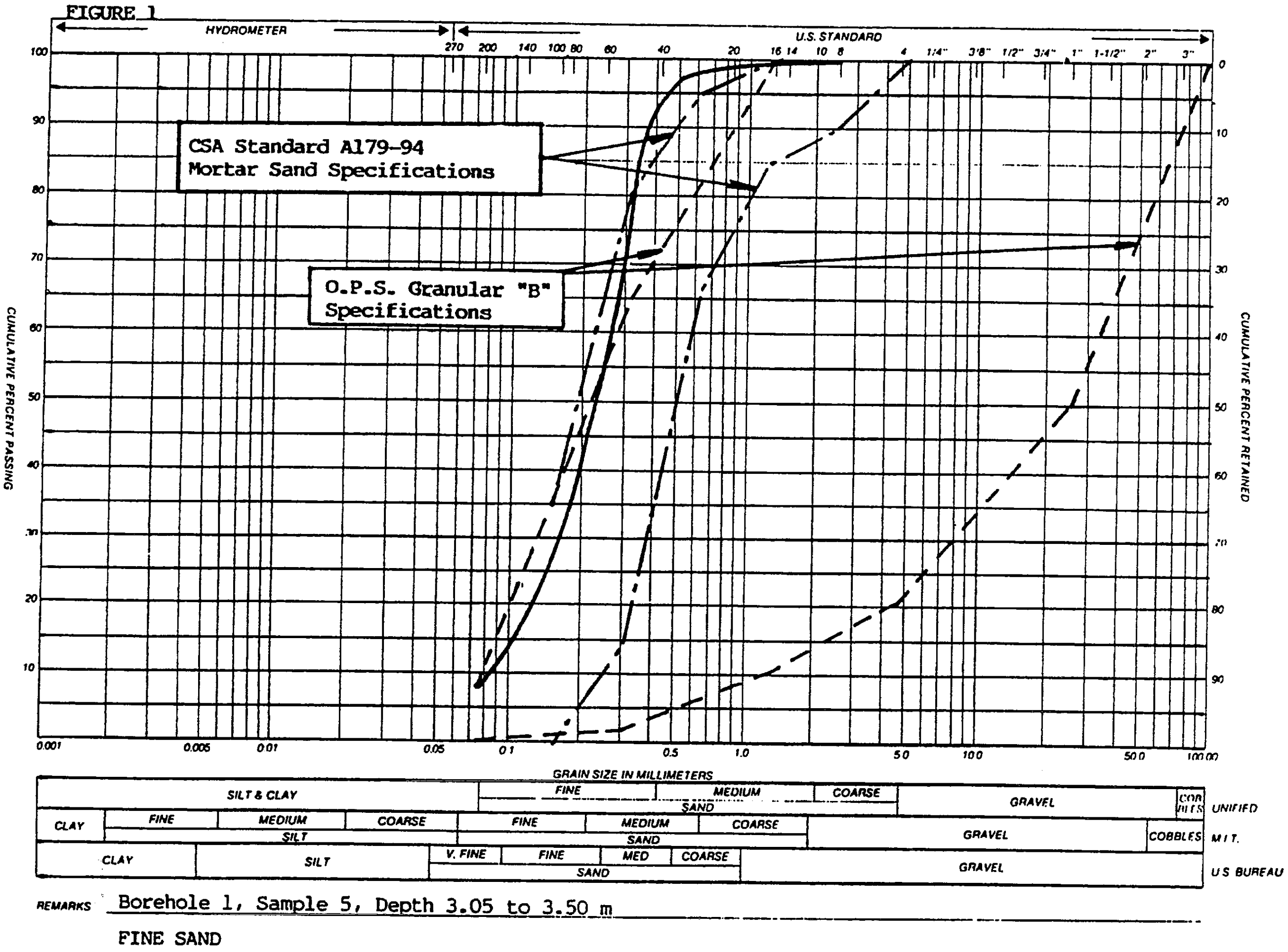

Table 1. Soil Testing Data

Location	Type of Test	Blows/ft
Upper 4m	SPT	6 to 20
	DCPT	4 to 23
Below 4m	SPT	12 to 24
	DCPT	15 to 63

minimize exposure time and disturbance of the soil excavated for shotcrete application.

- Excavation was carried out using a 3-panel sequence where buildings were remote from the excavation, and a 4-panel sequence at buildings.
- Berms with 1-metre ledges were left in place during tieback drilling. Berm maintenance included watering where considered appropriate.
- Shotcrete panel construction was completed the same day berms were removed.
- Vertical dowels, consisting of steel bars in 3 inch drilled holes, were installed at the shoring line prior to the start of excavation. The dowels, approximately 3 per panel, provided temporary face support during excavation and shotcrete application.
- Dowels in 8 inch holes on 4 foot centres augmented the smaller dowels at the most critical part of the excavation, to provide vertical support for the shoring wall should ground loss occur.
- To minimize ground loss potential, self-drilling MAI bars were installed and grouted to surface with sleeves to obtain design free zone lengths. Tiebacks were partially stressed the morning after panel construction, and fully stressed prior to excavation of the next lift.

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Tieback stressing program

Proof-tests

All tiebacks were proof-tested by cyclic loading to check free length and anchor performance. Early in the project, it was noted that elongation values in a significant number of proof tests indicated less-than-design free lengths. Where this occurred, the tests were repeated using higher proof loads to break bonds and mobilize longer free zones.

Proof testing showed 99.5 percent of tiebacks met anchor capacity requirements. Tieback anchors that could not resist the proof load were replaced.

Lift-off tests

Lift-off tests were performed wherever loss-of-load was suspected, and to ensure inspection records were complete. In total, 4 percent of tiebacks were lift-off tested, and test results generally confirmed expectations. Seven random lift-off tests, conducted on upper level tiebacks when excavation depths were 20 to 25 feet, indicated tieback loads were 86 percent of design load on average.

Load cell readings

Load cell data was obtained from two locations, as shown in Fig. 3. At the third and fourth tieback rows, load cell readings indicated tieback lock-in values were 110 and 114 percent of design load respectively, and initial load losses were 18 and 22 percent of lock-in values respectively. With both load cells in place, the remaining 20 feet of soil was excavated in 45 days and additional load losses of approximately 5 percent of lock-in value were measured. Final load cell readings, taken one month after excavation was completed, indicated tieback loads were approximately 84 percent of design load.

Performance tests

Four tieback performance tests were carried out. Three production anchors, with bond lengths ranging from 22 to 54 feet, were tested initially. At the maximum test load of 60 kips, anchor forces ranged from 1.1 to 2.6 kips/feet. The fourth test, carried out on a non-production tieback with the bond length shortened for testing purposes, demonstrated an anchor adhesion capacity of 7.3 kips/feet. The data from this test are plotted in Fig. 4. The ultimate capacity of the tiebacks was not determined.

Fig 3. Section A

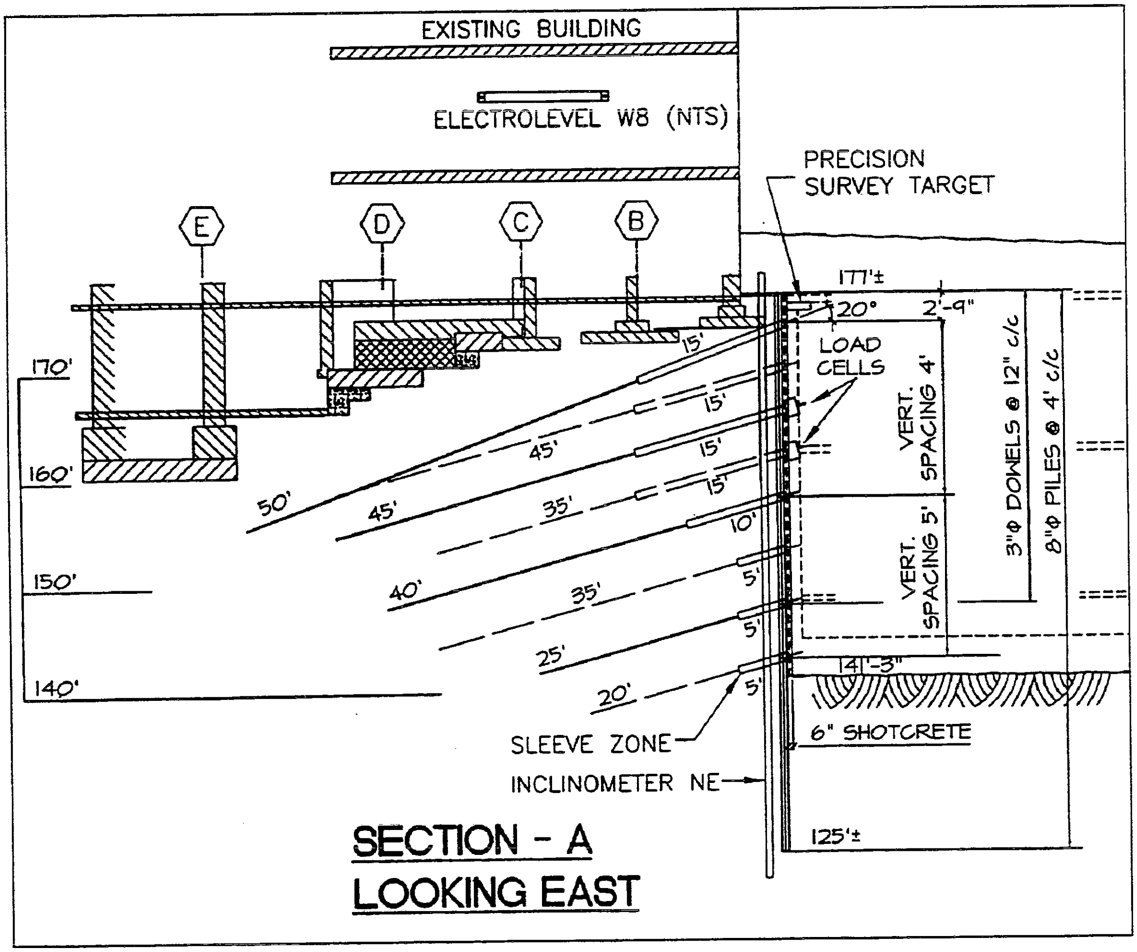

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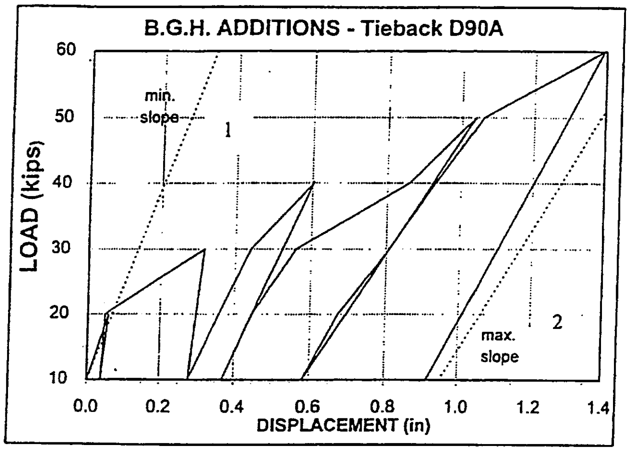
Fig 4. Performance Test Plot.



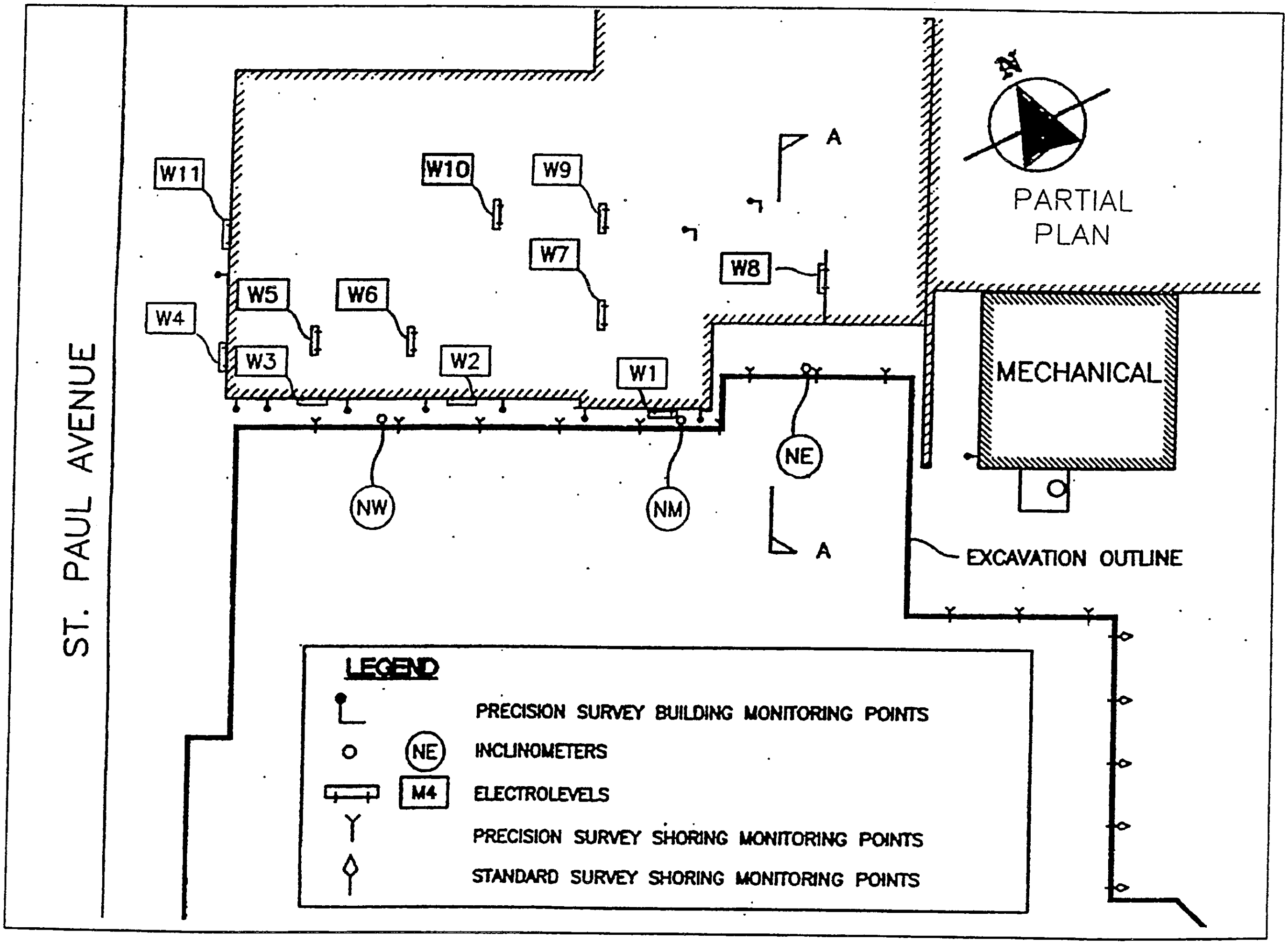
1 - min free length = 80% sleeved length + jack length.
2 - max free length = 50% anchor length + sleeved length + jack length.

Monitoring program

Several forms of monitoring were used to track shoring performance during constrution (see partial plan in Fig. 5). A total of eight inclinometers were installed on cuts greater than 16 feet deep distributed around the site, and concentrated at buildings. Electrolevel installations, totalling sixteen, were located on hospital foundation walls and beams. Precision survey data was collected from thirty-two targets fixed to the shoring wall on 3-metre centres, and sixteen targets fixed at appropriate points on adjacent structures.

Inclinometers were read weekly, and processed and checked the same day. Electrolevels were read several times a week initially, to observe how the data fluctuated, and were read at least once a week until shoring installation was completed. Baseline precision and standard survey readings were recorded and available for comparison with other monitoring data whenever appropriate.

Fig 5. Monitoring Instrument Locations



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Monitoring results

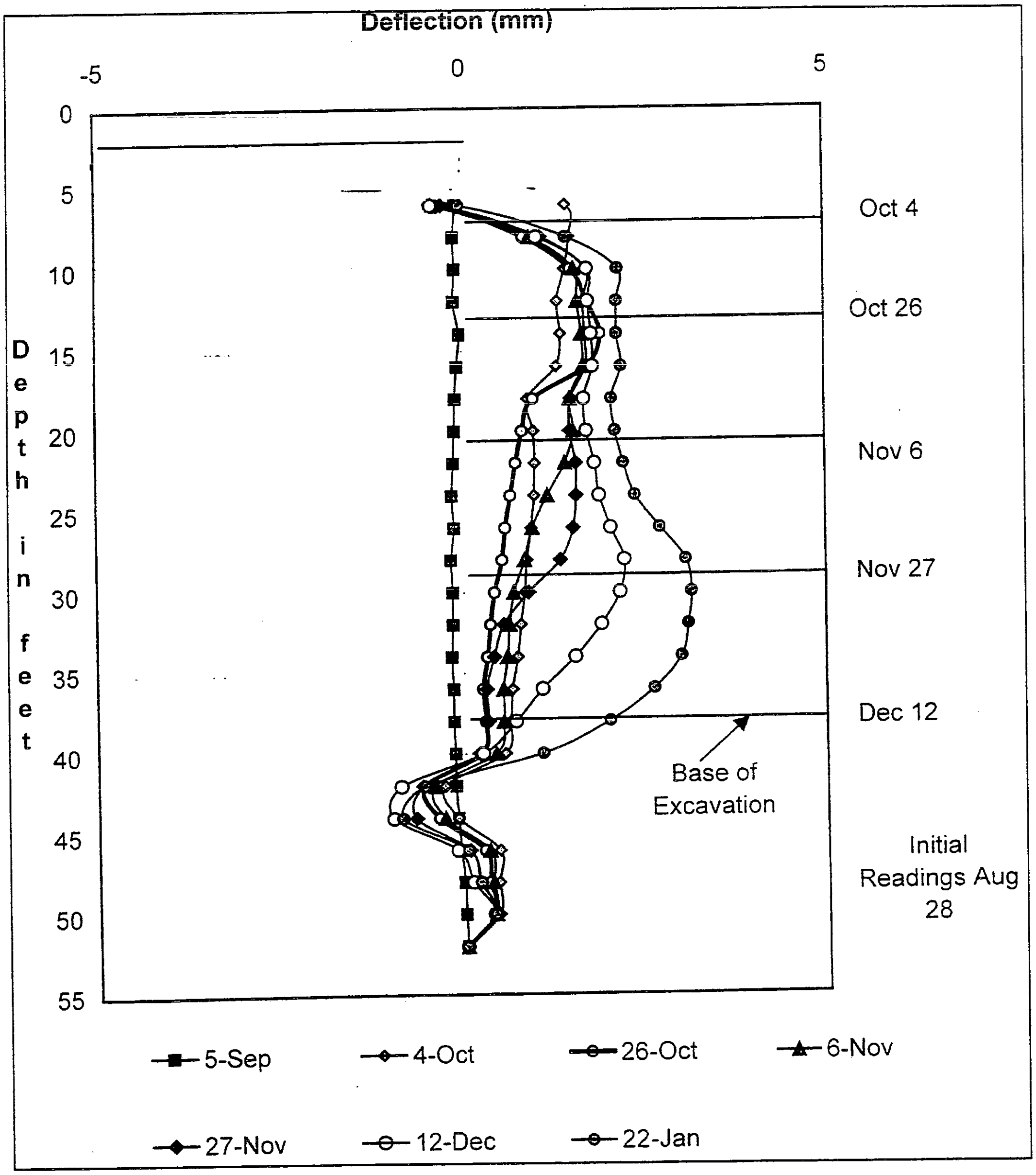
Inclinometers

The deepest part of the excavation, as shown in Fig 3, and Fig 5, which coincided with the highest part of the hospital structure, was instrumented with precision survey targets, inclinometer NE, electrolevel W8, and two load cells.

Inclinometer plot NE, displayed in Fig. 6, showed characteristic into-site "bulges" concurrent with local excavation of each four-foot lift. The time period between lifts, from initial berm excavation to final tieback stressing varied from four to fourteen days. The maximum displacements, or "bulges", generally occurred near the base of the lift most recently excavated. Above the active lift, where shotcrete wall construction and tieback stressing had been completed, inclinometer displacements were negligible. For example, between October 26 and December 12, inclinometer plot NE indicated almost no change between depths 10 and 16 feet, while 1.4 millimetres of into-site displacement was measured at 28 feet.

Upon completion of all excavation and shotcrete wall construction, the maximum relative into-site displacement was 2.2 millimetres. Additional post-excavation displacements, mainly attributed to compaction vibrations, increased the maximum displacement to 3.3 millimetres or 0.03 percent of the excavation depth.

Fig 6. Displacement Plot for Inclinometer NE



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Electrolevels

The electrolevels used on the BGH project consisted of beams, generally 1m long, containing an electrolytic tilt sensor, which outputs a voltage proportional to the tilt of the sensor. A diagram of the sensor is shown in Fig. 7.

The electrolevel beams were levelled and fixed to concrete surfaces with anchor bolts, and then the sensors were levelled to give baseline readings of zero.

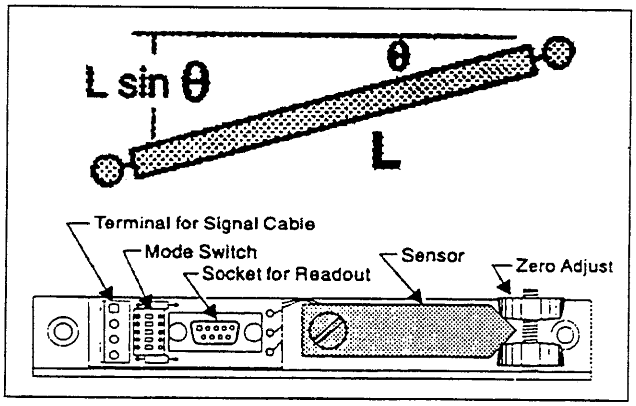
Electrolevel readings from four instruments installed inside the hospital building and W8 at section A, are presented in figures 8 and 9 respectively. Examination of the plots reveals that the readings are sensitive to temperature fluctuations.

Changes in relative displacement over a one-metre electrolevel beam length ranged from 0.2 to 0.7 millimetres, without temperature calibration, upon completion of the excavation. Considered over the span of the walls or beams supporting the instruments, the readings indicated average total building displacements ranging from 0.7 to 3.6 millimetres. Factoring in the temperature effects, displacements were more realistically on the order of 0 to 0.4 millimetres.

Precision surveying

Unlike the other forms of monitoring on the site, precision survey readings were based on a geodetic datum. At section A, shown in Fig. 3, building target readings indicated a maximum horizontal displacement of 3 millimetres into-site, and maximum vertical displacement of 1 millimetre down. Shoring target readings indicated 1 to 2 millimetres horizontal displacement into-site, and vertical displacements between 1 millimetre down and 3 millimetres up.

Fig 7. Electrolevel Sensor Diagram



Conclusions

Inclinometer and electrolevel readings, confirmed by precision survey readings, indicated ground movements were limited to 0.03 percent of the height of the cut, and building settlements were limited to 1 millimetre. Based on shoring performance at the BGH site, tied-back shotcrete can be used in essentially normally consolidated, fine to medium grained, loose to compact sand to achieve near-negligible ground and adjacent structure movements.

On the BGH site, face protection measures and a suitable tieback stressing program were effective in assisting ground movement control. Tieback testing and monitoring helped confirm design and construction methodology on a timely basis, and furnished valuable data on wall and anchorage behaviour. Monitoring also increased the comfort level of all concerned parties.

Higher-than-anticipated ultimate anchor adhesion capacities in the sand could be capitalized on with further testing and experience working with tied-back shotcrete in this type of material. Serving as the matrix of the composite shoring wall, the sand exhibited suitable characteristics, as evidenced by the inclinometer plots showing negligible movements after construction was completed, and only minor movements subsequent to completion of excavation most likely caused by compaction vibrations.

References

[1] PetoMacCallum Ltd, Consultant Engineers, 1999. Geotechnical Report for Brantford General Hospital.
[2] Ansari, Nadir. Soil Nailing Earth Shoring System. July/ August 1992. Construction Canada.
[3] EL Beam Sensors Manual, 1996. Slope Indicator.

Fig 8. Electrolevel Results

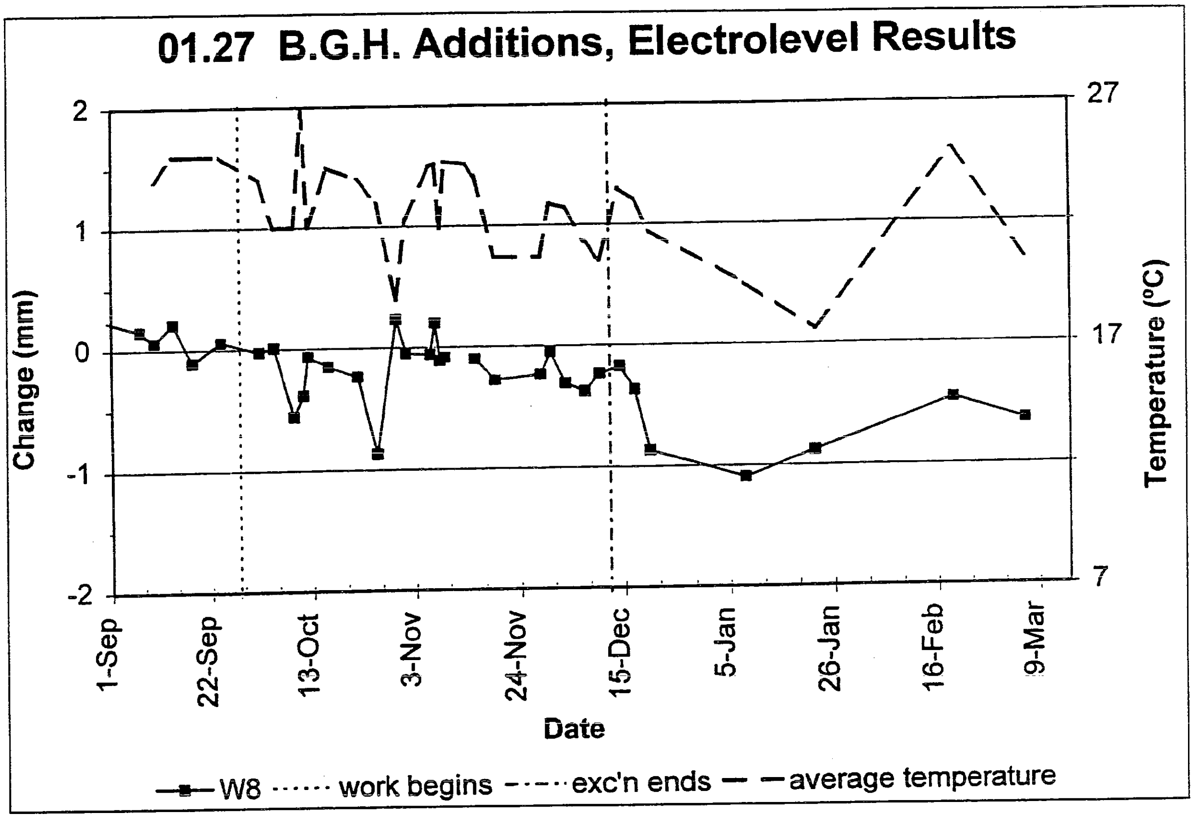
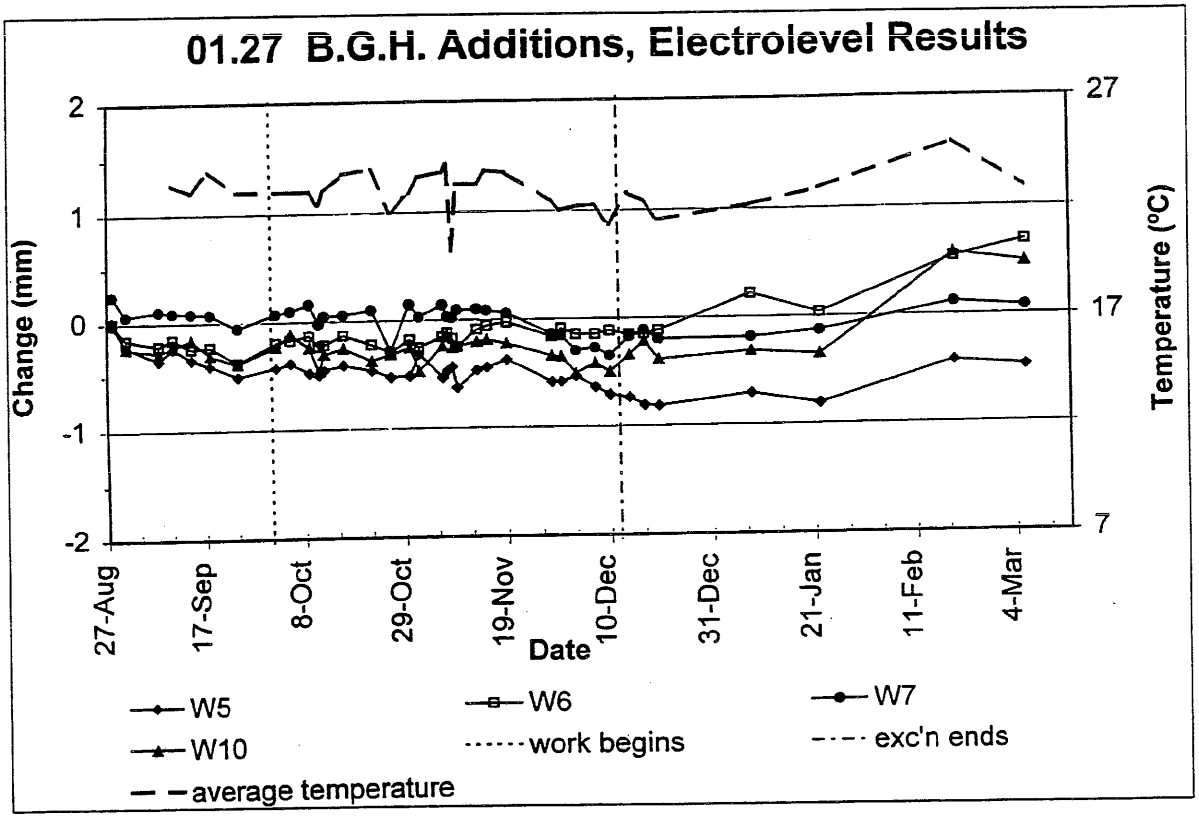


Fig 9. Electrolevel Results at Section A



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