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DESIGN AND INSTALLATION OF A NEW SETTLEMENT- INCLINOMETER DEVICE

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ABSTRACT: A new miniature settlement-inclinometer device (SID) system has been designed and built at the University of British Columbia for use in monitoring soft soil movements. The great advantages are that it can be easily installed using the university's in situ testing vehicle and both vertical and horizontal deformations can be measured in a simple automated operation. This paper describes the design, installation and operation of the SID system. The first experience with it is promising and it is expected to provide valuable information on the magnitude and direction of soil movements under all types of static loading.

INTRODUCTION

The SID is a miniature biaxial slope indicator with the ability also to monitor vertical deformations at preselected intervals below the ground surface. The overall length is only 360 mm and the outside diameter is 16 mm so that it can pass a much smaller radius of curvature than the usual slope indicators. The device is designed to operate in standard 48 mm OD, 38 mm ID, inclinometer casing which is small enough to be installed using the UBC in situ testing vehicle (Fig. 1). This method of installation provides a more rapid and economical alternative to standard drilling and grouting techniques.

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FIG. 1 Photo of UBC in situ testing vehicle

The SID contains a liquid level tilt gauge similar to one described by Burland and Symes (1982) for laboratory use. It can measure angles simultaneously on two perpendicular axes and a tiny electric motor rotates the gauge 180 degrees for opposing tilt readings. (Fig. 2) This automation permits a complete set of inclination readings to be taken at each elevation with a single pass of the instrument. For settlement measurements, small magnets are installed on "spiders" outside the casing with freedom to move vertically as described by Burland et al. (1972). As the instrument is moved up the casing the level of the magnets is recorded automatically.

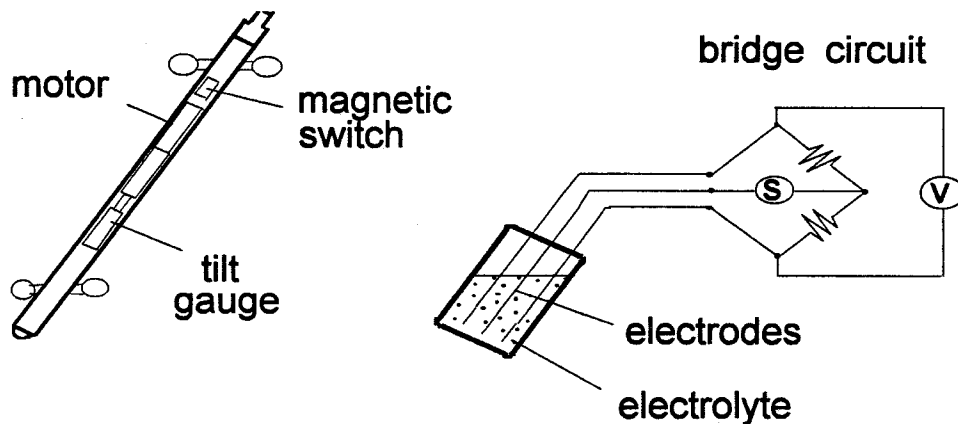


FIG. 2 - Motor/tilt gauge assembly and tilt gauge representation

System design and calibration

The probe was developed to be as small as possible to provide biaxial inclination measurements as well as vertical settlement readings. The design and assembly were separated into two phases. The first phase included the design and construction of the miniature probe and a crude readout /control unit. The second phase involved the design of an automatic control/data logging unit and some communication/processing software. In the first phase, research was done on various types of inclination and magnetic field sensors. A small magnetic reed switch was chosen along with some polarized alnico bar magnets for the settlement measurements. A biaxial electrolytic tilt gauge was selected for the inclination measurements as it has a very small diameter and initial testing showed it had sufficient resolution. A miniature geared motor to rotate the inclination sensor 180 degrees (which allows a complete set of inclination readings to be taken in one pass) was also purchased.

Consultation with inclinometer manufacturers provided insights into potential problem areas. The electrical cable used between the probe and the readout should be scrutinized for strength, durability, water resistance and twist under tension. The cable distance markings should provide as accurate and repeatable a distance as possible. The quality of the wheel bearings used and the repeatability of the mechanical wheel/spring assembly play an important role in the system accuracy. These concerns, as well as the ones involving waterproofing, were all considered in the mechanical design process. Tradeoffs were made to accommodate the most important design criterion, that being the overall probe dimensions. The mechanical design, machining and the electrical wiring were then completed. A crude instrumentation box was built to control the motor and to switch inclination axes on the high resolution readout. This box also housed the tilt gauge signal conditioning module, a buzzer (for the magnetic reed switch) and rechargeable batteries.

After the device was constructed, many calibrations and tests were done. Each inclination axis was calibrated with the use of a machine dividing head and a precision bubble level. These calibrations determined that a 3rd order polynomial correction was needed to give an accuracy of about 50 seconds of arc. An electronically controlled temperature bath was used to determine the temperature effects on the tilt gauge. At angles less than 15 degrees and temperatures less than 20° C, the influence of temperature on the inclination readings was small as shown in Fig. 3. Tests were also done in a 5 m long casing affixed to a wall and comparisons made with a standard Sinco inclinometer, showing good agreement between both probes. Another test involved bending a piece of casing and measuring the point at which the miniature probe as well as a standard size inclinometer would get stuck (Table 1). The miniature probe can maneuver a radius about 1/3 that of the standard commercial probe. It has a gauge length of only 200 mm and, therefore, compared to the standard probe, 2 1/2 times as many readings must be taken to have 1 reading per gauge length. Although this

gives better curve definition , it requires more field time and makes automation highly desirable.

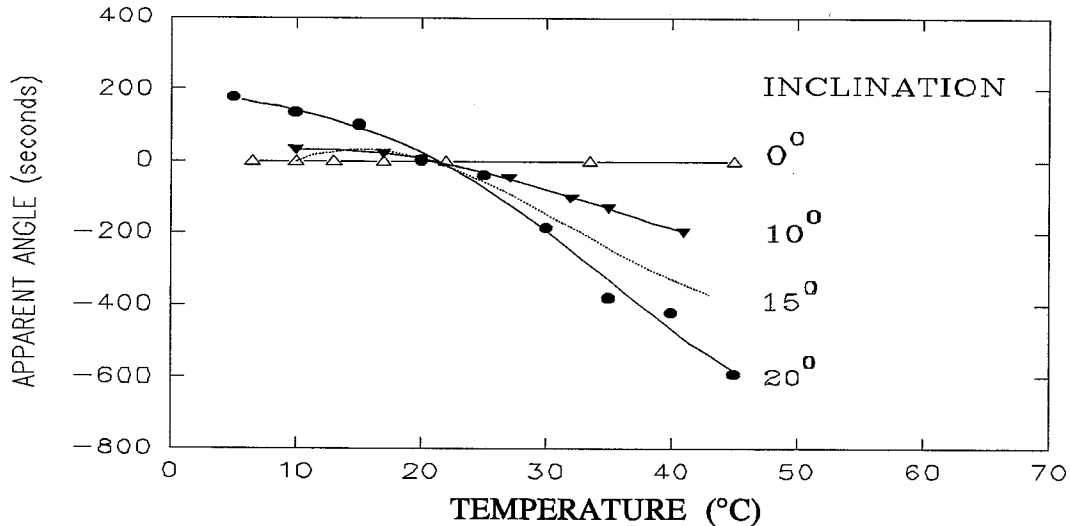


FIG. 3 - Temperature calibration

A casing installation was then completed at a highway construction site and some initial test data gathered. The device functioned well but it was evident that the automated data collection/processing system was needed. Phase 2 involved modifying the original instrumentation box, building a depth wheel, developing some PC software and establishing some standardized procedures.

Operation

At each measuring depth, an 8 bit microcontroller automatically cycles the motor and the readout unit to obtain, display and store each of the four inclination readings. Data and prompts are provided via an alphanumeric LCD display while the user can select modes and data collection points with two push-button switches. A depth wheel assembly, with an optical encoder, attaches to the top of the casing and provides depth information for each magnetic reed switch closure. An overview of the SID system is shown in Fig. 4. Once all the data has been collected in the instrument box it may be transferred to a PC compatible computer either in the field or upon returning to the office.

The software that runs on the PC compatible queries the user for site/test specific information and then gets the data from the instrument box via the RS232 serial port. The raw data is stored in a main file and the program separates out inclination and magnetic settlement records, storing each in a separate file. A 3rd order polynomial calibration correction is performed on the inclination data and it is then stored in a Sinco "RPP" format file. This format can be directly read by the commercial analysis program called "GTILT" (by Mitre Software).

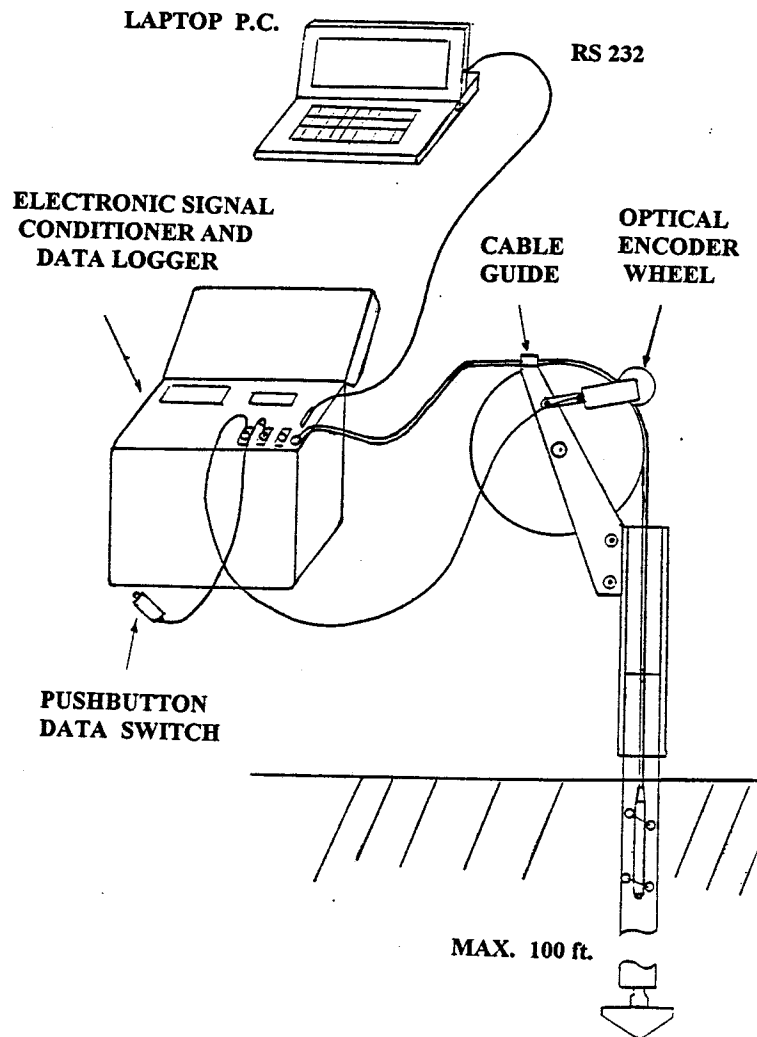


FIG. 4 Overview of UBC's SID system

The test procedure has been standardized so that each test is readily compared to past data as well as providing a check for equipment calibration and maintenance. The procedure describes important requirements such as always orienting the wheels in the same direction, giving the instrumentation time to warm up, positioning the cable to the nearest millimeter and monitoring a checksum histogram. Batteries are charged up and cable and equipment operationally checked before each use. Equipment is cleaned, inspected and calibration is checked after returning from the field. These guidelines help ensure data repeatability and integrity.

Field installation

The system was designed to be installed with the UBC In Situ Testing truck by pushing and/or jetting a steel HQ casing (75 mm ID, 87 mm OD) into the 44 mm diameter hole left after a piezocone penetration test probe is removed. This vehicle has a net push force of about 9000 kg. thereby restricting pushing installations to soft soils. The jetting option can be employed to aide installation in slightly stiffer soils. A plastic conical shoe is used to plug the bottom of the casing and it is pushed into the harder soil layer below. Water jetting through resistant soil layers can be achieved with a quick connector linking the shoe to a hose that allows water to be pumped to the tip. At the end of the installation, the quick-connector is disengaged by means of a wire line and the hose is removed.

The grooved inclinometer casing and the settlement spiders are then inserted into the steel casing. Spacing collars are fixed to the inclinometer casing at specific points to push and position the spiders. The spiders have an inherent spring action which allows the free end to expand to the ID of the HQ casing (see Fig. 5). The front of the inclinometer casing has a quick connector attached to it

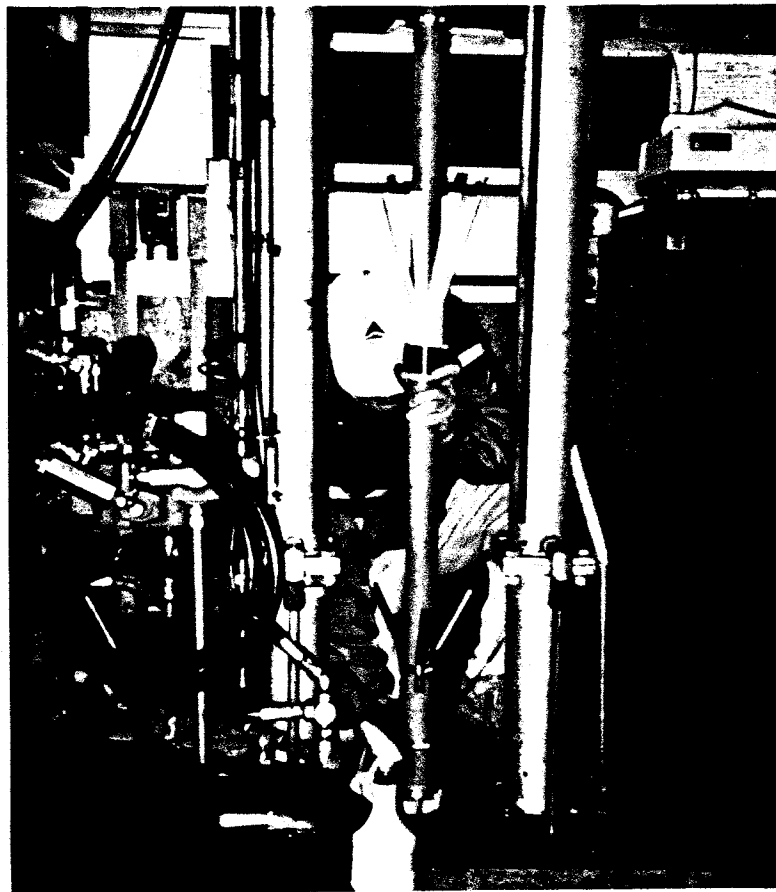


FIG. 5 Photo of spiders being inserted into casing

so that when the casing is at the bottom it latches on to the conical tip. This prevents the inclinometer casing from being floated up when the outer HQ casing is removed. The inclinometer casing is oriented to have its grooves aligned parallel and perpendicular to the main deformation axis of the structure to be monitored.

The steel casing is pulled out using the hydraulic rams of the truck leaving the conical tip, inclinometer casing and spiders in place. The annular space between the soil and the inclinometer casing is filled by the soft soil moving in against the casing. The basic steps in installation are shown in Fig. 6.

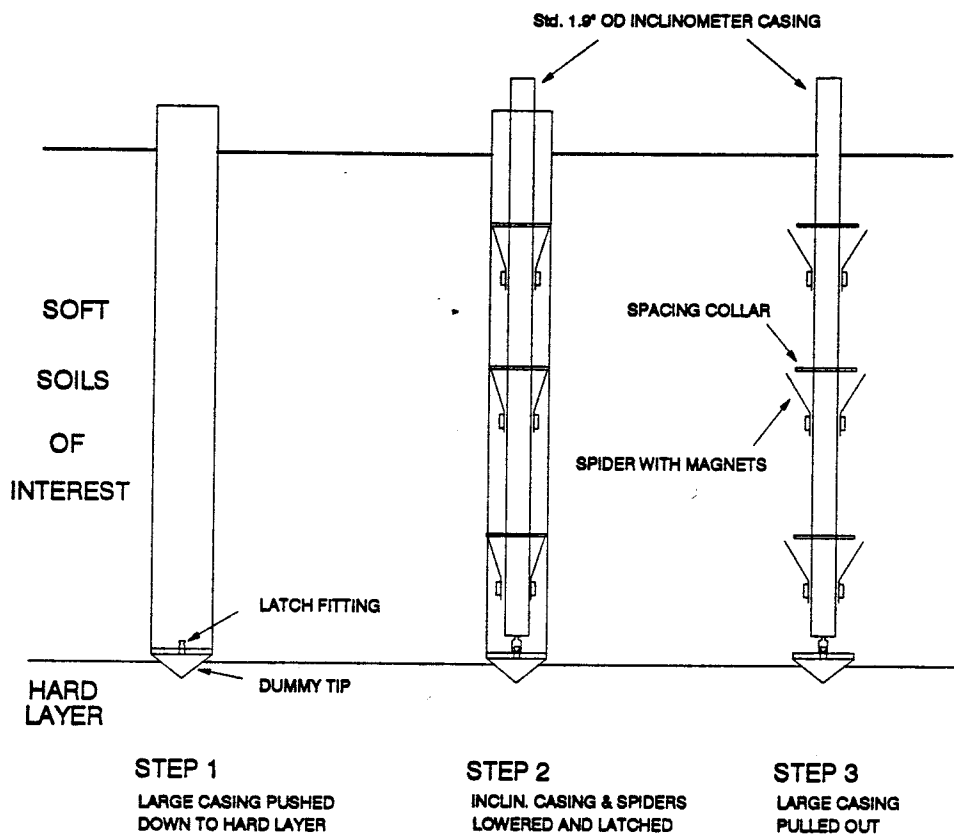


FIG. 6 Installation process

Field results

Initial field results during phase 1 presented some interpretation difficulties because a standardized procedure for the readings had not been developed and some site changes had been made. With the completion of phase 2 these problems have been overcome and both the settlement and inclination data appear to be consistent and reasonable.

The site for this experimental installation is located on the slope of a highway embankment which will eventually be 9 m high. Figure 7 is a photo of the site showing some data being collected. Figure 8 shows a cross-section where the SID casing was installed. At the time of installation it was expected that construction of the embankment would proceed without delay. Unfortunately this work has been postponed and consequently the subsurface movements have been small. When the casing was installed, the fill was less than 1 m deep. It is now about 2 m deep and the surface area has been increased so the horizontal movements are complex. This is reflected in the curves shown in Fig. 9. The measured movements are very small but they indicate a consistent trend with time except near the top where the casing is not stable.

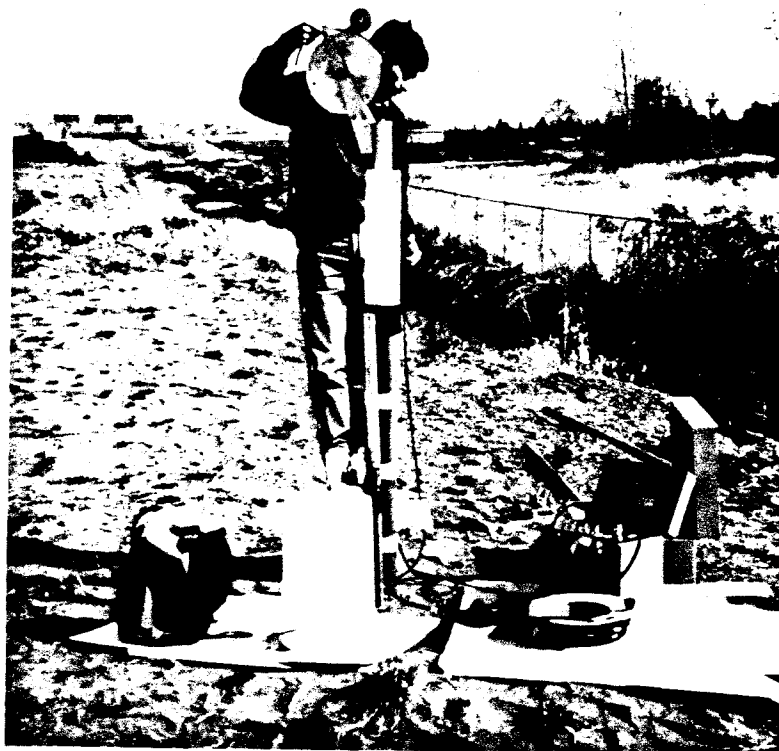


FIG. 7 Photo of site showing top of fill and field readings

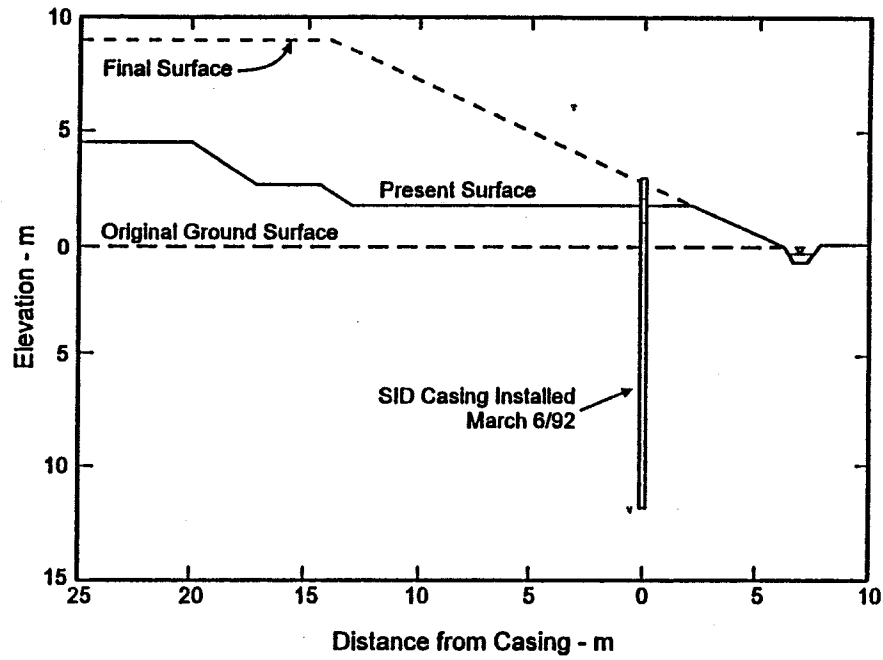


FIG. 8 Cross-section of site

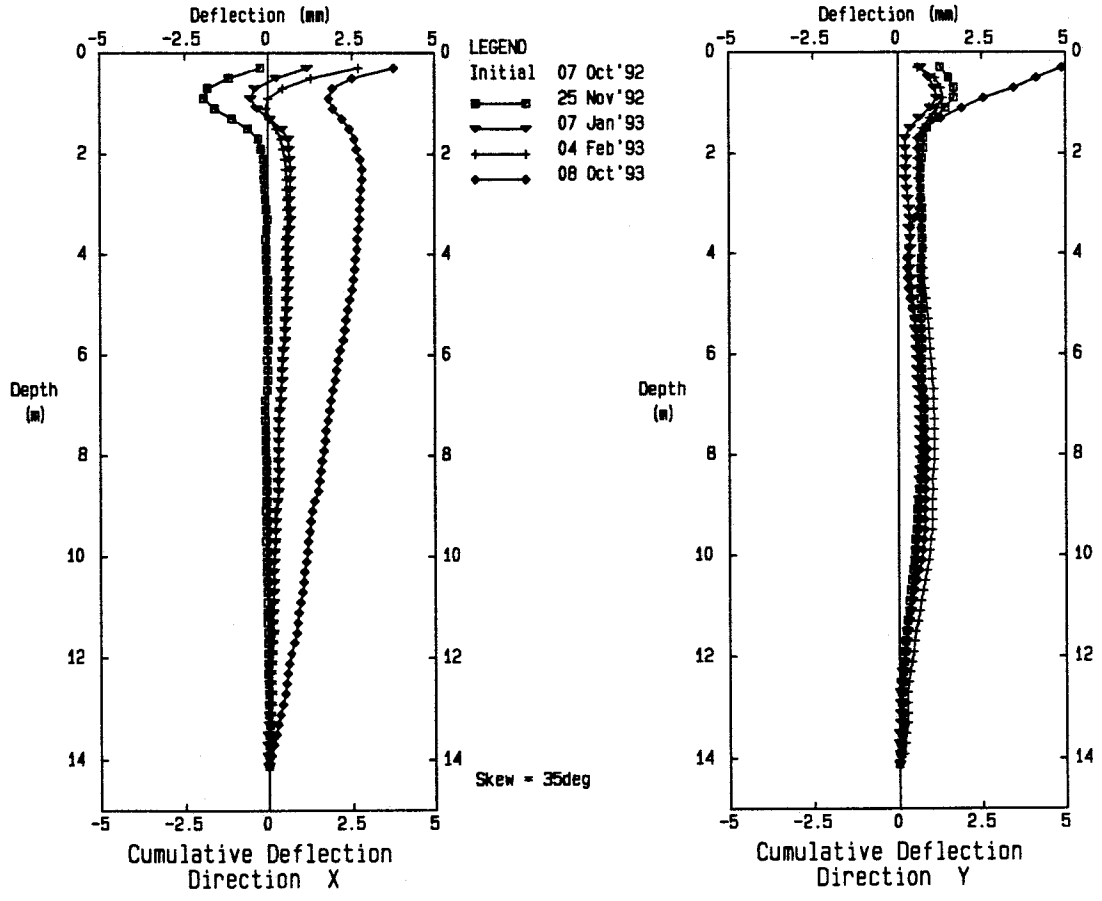


FIG. 9 Horizontal Deflection Data

The sand fill was placed over 12 m of very soft soil. The measurements during a 12 month period show a maximum settlement of about 0.06 m (Fig. 10). At first the depth to the bottom of the inclinometer casing was determined by lowering the probe and manually sensing the change in weight when it reached the bottom of the casing. This would give a depth referenced to the top of the casing and subsequent settlement readings were taken with reference to the top. This manual method proved to be unsatisfactory but when the depth wheel was added (Fig. 4) in September 1992 the readings improved. Finally it was concluded that the lowest magnet would be a better reference point and that the measurement of the difference between adjacent magnets eliminated cumulative errors. This technique was used for the recent surveys. Future installations should include a magnet mounted on the bottom of the casing to act as an even better reference point for the settlement measurements.

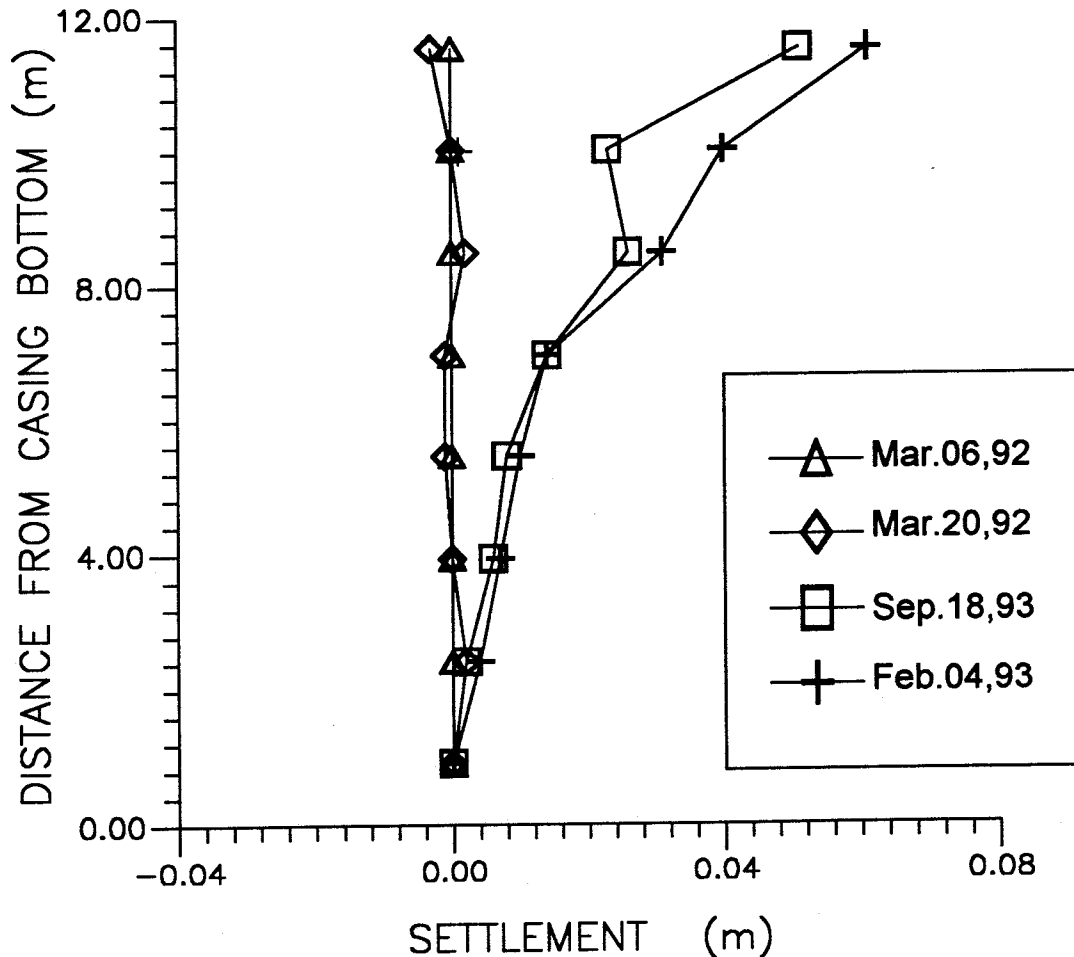


FIG. 10 Settlement Measurements

Discussion

The main difference between the UBC SID and commercially available probes is its reduced dimensions (Fig. 3). The SID is only 360 mm long, while standard commercial probes are typically 650 mm long. This feature allows much more bending in the casing before the probe gets stuck so it is especially suited for soft soil sites where expected deformations are high. Maximum allowable bending for both the SID and standard sized inclinometers was tested in the laboratory as shown in Table 1.

TABLE 1 - Casing Bend Comparison

Description	UBC Probe	Standard Commercial Setting
Probe diameter (mm)	16	25
Probe gauge length (mm)	200	500
Probe total length (mm)	360	650
Minimum bending radius for a 48 mm plastic casing (mm)	1200	4200
Maximum angle deflection over a gauge length (degrees)	4.78	2.40

Unlike other inclinometers, settlements can also be measured with the SID along the same casing by means of the magnetic spiders installed around the outside of the casing. The spiders are PVC sleeves (with epoxy attached magnets) that can move up and down freely with the soil outside the casing. The position of the magnets (or magnetic field) is sensed by a magnetic switch installed in the probe. The relative depth is automatically determined by the average of the switch-on and the switch-off depth at each spider. When using the optical encoder and automatic instrumentation box, relative depths have a sensitivity of 1 mm and a repeatability of ± 2 mm.

Electrolytic tilt sensors have been available for many years but this precision biaxial model has only been offered recently. Temperature effects appear to be minimal for the ranges and temperatures of intended operation. If the operating temperature exceeds about 25°C with an apparent angle greater than 10 degrees, it may become necessary to include temperature compensation calculations in the post processing software. Long term stability of the sensor and its associated signal conditioning unit has still to be determined. Sensitivity and repeatability appear to be good. Some commercial inclinometers, such as Applied Geomechanics models 732 & 733, are based on other models of electrolytic tilt sensors so it is reasonable to expect adequate performance from the SID.

Conclusions

The SID casing installation using the UBC in situ testing vehicle worked very well at the first experimental site. The installation process proved to be

quick and easy. The automation of the data collection and processing has proved to be a great help in speeding up both the field work and the analysis while eliminating some of the potential human errors. The commercially available program "GTILT" has been easy to use and further improves the ease at which the database can be updated and presented.

The SID has performed well but more data and test installations are required to confirm its capabilities. The inclination performance of the SID seems comparable to larger commercially available units and the settlement data (under automatic monitoring) has a high degree of sensitivity and repeatability. During the next year it is planned to install more casings to evaluate the instrument further.

Acknowledgments

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APPENDIX. REFERENCES

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