Sensor installation for field monitoring in expansive soils

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ABSTRACT
An aging infrastructure is facing great challenges due to problems associated with expansive soils. To develop a clear understanding of complex soil-pipe-atmosphere interactions, this paper presents a sensor installation method for field monitoring of expansive soils. Sensors for measuring water content, soil suction, soil pressure, temperature, and displacement were installed at a test section in a residential area of Regina around a 50 year old asbestos cement water main. To minimize soil disturbance, necessary precautions were undertaken and specialized tools were used for placement of sensors.

RÉSUMÉ
Une infrastructure vieillissante fait face à de grands défis dus aux problèmes liés aux sols expansibles. Pour comprendre clairement les interactions complexes du système sol-pipeline-atmosphère, cet article présente une méthode d'installation de sonde pour la surveillance des sols expansibles. Des sondes pour de la teneur en eau, l'aspiration du sol, la pression de sol, la température, et la mesure du déplacement ont été installées à une section d'essai dans un secteur résidentiel de la ville de Regina autour d'une conduite en amiante-ciment vielle de 50 ans. Pour réduire au minimum la perturbation de sol, les précautions nécessaires ont été entreprises et des outils spécialisés ont été utilisés pour le placement des sondes.

1 INTRODUCTION

Civil infrastructure assets are facing a great challenge due to problems associated with expansive soils. The breakage rate of asbestos cement (AC) water mains in Regina has doubled from 0.13 breaks/km/year in 1985 to 0.27 breaks/km/year in 2005 (Hu and Hubble, 2005). The City of Regina spends an estimated $1 million per year to repair breaks in its 850 km long water supply network, about 70% of which is AC pipe generally over 40 years old. The increase in pipe failure is attributed to several factors including (a) pipe (material and age), construction (method and maintenance), soil (type and composition), and climate (precipitation and temperature). Seasonal variations in climatic conditions result in alternate saturation-desaturation in all local soils. Given its highly expansive nature, Regina clay exhibits periodic swelling and shrinkage behaviour causing severe distortions that eventually leads to rupture of the pipelines. The sustainable (cost effective, environmentally friendly, and socially viable) management of buried infrastructure requires a clear understanding of the complex soil-pipe-atmosphere interactions in the expansive Regina clay.

This paper presents a sensor installation method for field monitoring of expansive soils around an AC pipe section. A set of sensors was chosen to determine water content, soil suction, soil pressure, temperature, and displacement at regular intervals of time. The sensors were installed at a test section in a residential area of the city where an AC pipe was installed about 50 years ago. To minimize soil disturbance, necessary precautions were undertaken and specialized tools were used for sensor placement at selected locations in the vicinity of AC pipe.

2 INSTRUMENTATION LAYOUT

Figure 1 gives the layout for field instrumentation at Cross Place in Regina. The various sensors were installed in the ground in May 2009. At the selected site, the current installation (with minimal soil disturbance) was completed adjacent to a previously instrumented section (that used soil excavation and backfilling) (Hu et al., 2008). The various sensors were installed at different depths (given in brackets in Figure 1) around the pipe that, in turn, was at an average depth of 2.1 m. The AC pipe was originally laid out along the street close to the park area some 50 years ago and subsequently covered with asphalt coating. Therefore, most of the moisture movement can be considered to be from the park area, namely: infiltration due to precipitation and park watering and evapotranspiration from the grass and trees.

Table 1 gives salient features of the selected sensors for field installation. Five types of measurements are recorded using specialized sensors: (i) water content through water content reflectometry probe; (ii) soil suction by thermal conductivity sensors and a jet fill tensiometer; (iii) soil pressure by total pressure cells; (iv) temperature by thermocouples; and (v) displacement by survey markers. The sensors were selected on the basis of simplicity in installation and operation, low maintenance, high data reliability, high precision, and low initial and operational costs. The first four types of measurement (except the tensiometer) are recorded by connecting the sensors to an automated data acquisition system. The jet fill tensiometer and survey markers are physically examined at regular intervals of time. The entire data is transferred to a portable computer for analyses.

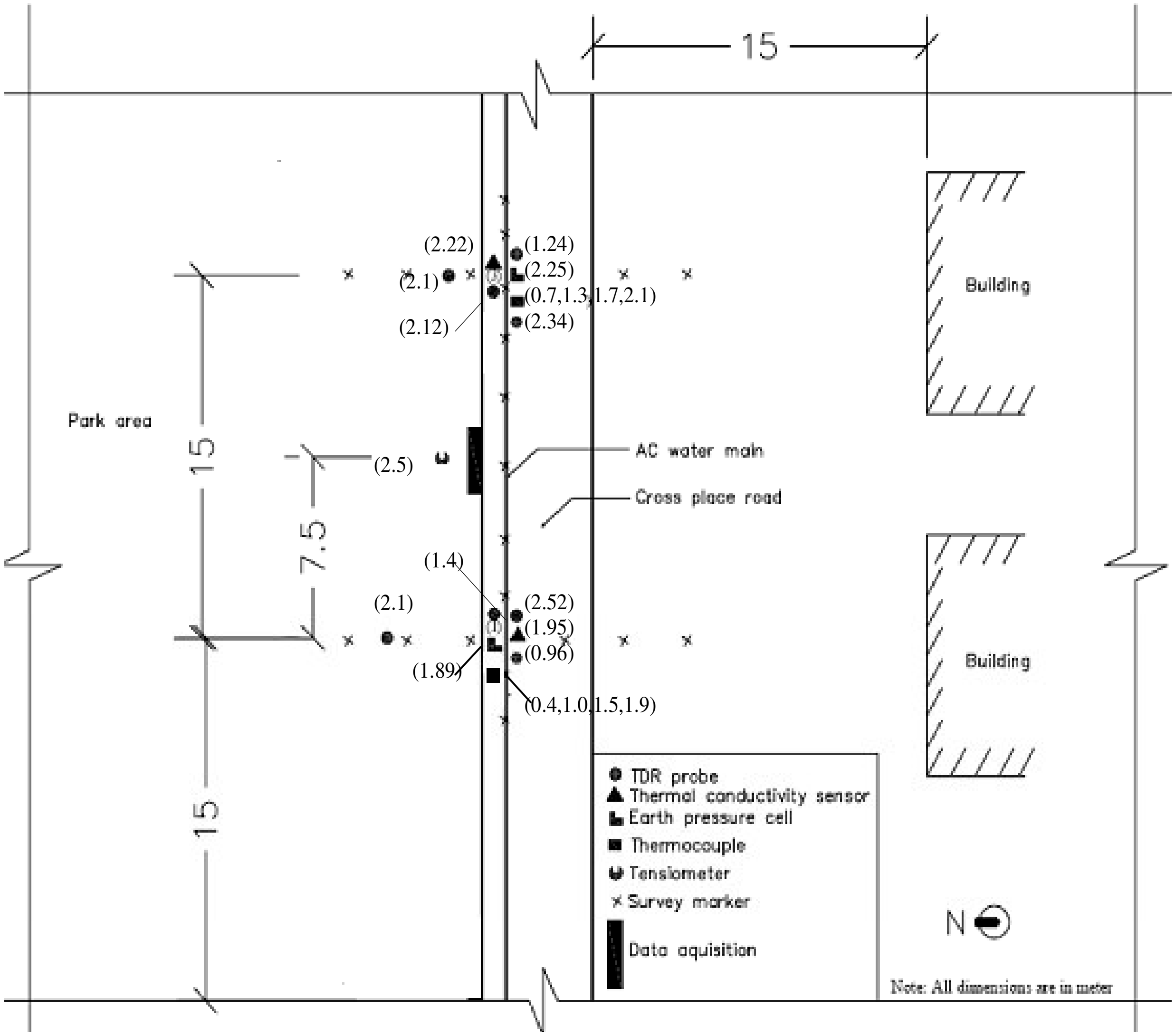


Figure 1: Layout of field instrumentation at Cross Place, Regina

Table 1: Salient features of the selected sensors

Measurement	Instrument Type	Quantity	Measuring Range and Estimated Accuracy*	Source
Water Content	TDR Probe (ThetaProbe ML2x)	8	0% to 50% (5%)	Delta-T Devices Ltd., UK
Soil Suction	Thermal Conductivity Sensor (FTC-100)	2	5 kPa to 1500 kPa (10 kPa)	GCTS Testing Systems, USA
	Jet Fill Tensiometer (2725ARl60)	1	0 kPa to 90 kPa (2 kPa)	Soil Moisture Equipment Inc., USA
Soil Pressure	Total Pressure Cell (TPC)	2	0 kPa to 100 kPa (0.5 kPa)	ROCTEST Ltd., Canada
Temperature	Thermocouple	8	– 190 ^{o}C to 350 ^{o}C (0.1 ^{o}C)	Veriteq Instruments Inc., Canada
Displacement	Survey Marker	32	No Limit (1 mm)	N/A

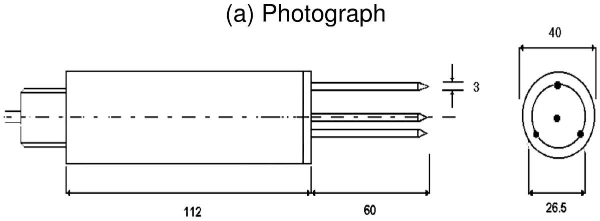
* The estimated accuracy is given in brackets

3 SENSORS AND INSTALLATION PROCEDURES

3.1 Water Content

Figure 2 gives the photograph and the dimensions of the ThetaProbe ML2x for measuring volumetric water content of the soil. A typical sensor comprises of four parallel conducting rods with one in the centre and three evenly distributed along an outer circle. Each of the rods is 60 mm long and 3 mm in diameter. A total of eight sensors were placed at depths ranging from 1.0 m to 2.5 m.

(a) Photograph



(b) Schematic diagram

Figure 2: ThetaProbe ML2x for water content

Figure 3 summarizes the installation procedure for ThetaProbe ML2x sensors. A 100 mm round borehole was drilled down to 100 mm above the prescribed depth. Thereafter, a smaller hole (around 35 mm) compared to the sensor diameter (40 mm) was cored with a special tool as shown in Figure 4. The bottom of this hole was gently tamped and levelled. The sensor was pushed through the hole until the probe body was fully entered. The rest of the borehole was backfilled with native soils above the sensor and the backfill was tamped to a density similar to that of the surrounding soils.

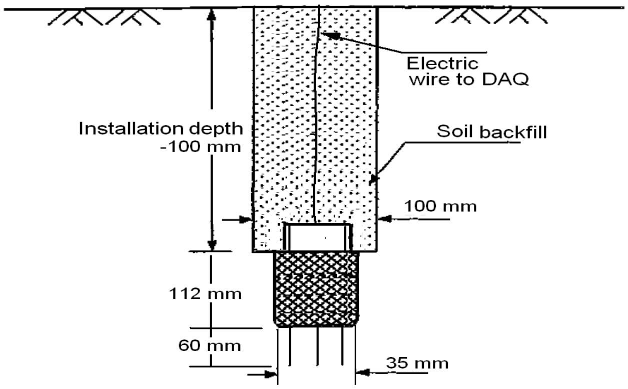


Figure 3: Installation of ThetaProbe ML2x

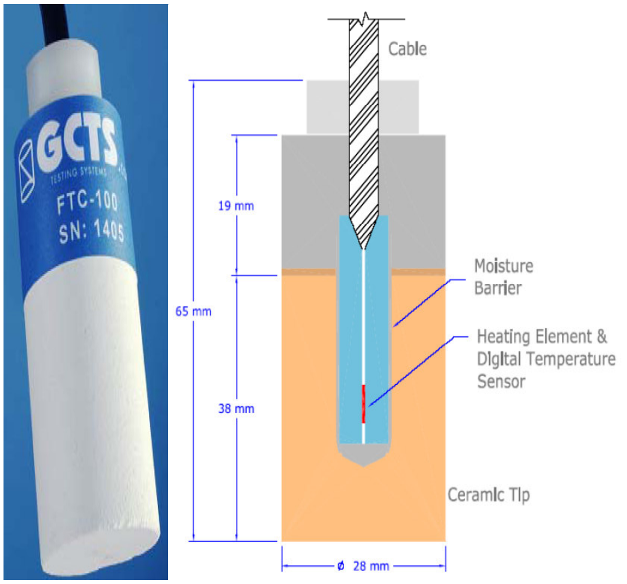
Figure 4: Special coring tools for ThetaProbe ML2x

A separate borehole was made for each sensor to minimize errors due to sealing imperfections. The presence of air pockets around the rods is known to result in an underestimation of water content. Small rod bending (> 1 mm out of parallel) increases the likelihood of air pockets around the rods during insertion. Stones, roots, and earthworm holes in the vicinity of the rods affect the water content measured by the ThetaProbe ML2x. Care was exercised during auguring to avoid the above-mentioned issues.

3.2 Soil Suction

3.2.1 Thermal Conductivity Sensor

Figure 5 shows the photograph and a schematic diagram of the FTC-100 used for measuring suction in unsaturated soils. The sensor indirectly measures the matric suction based on the thermal conductivity of a specially designed ceramic block. Two FTC-100 sensors were installed at depths of 1.9 m and 2.2 m using specialized tools as shown in Figure 6. The sensors were completely saturated in water before installation.



(a) Photograph (b) Schematic diagram

Figure 5: FTC – 100 for soil suction

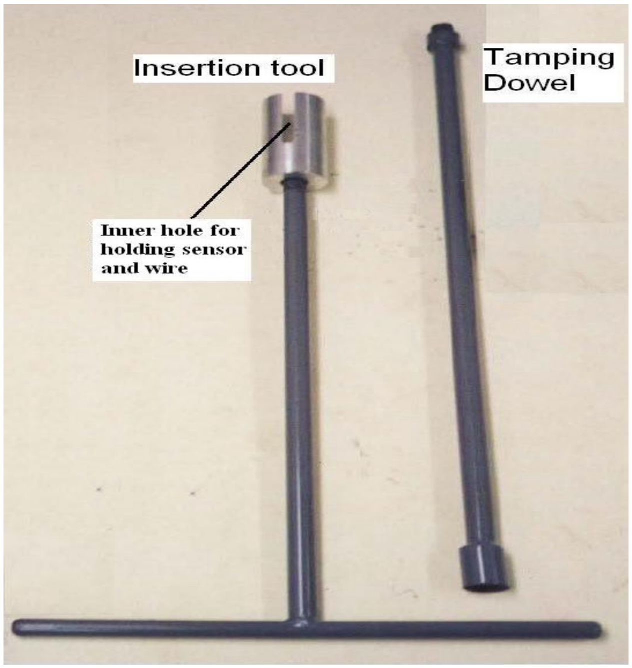


Figure 6: Installation tools for FTC - 100

Figure 7 gives the installation procedure for FTC – 100. First, a 100 mm circular borehole was drilled to about 30 mm above the prescribed depth. Second, a smaller hole (28 mm internal diameter) was cored to about 38 mm deep below the bottom of the borehole with a similar special coring tool as shown in Figure 4 but a diameter of 28 mm. A tamping dowel was used to slightly stamp the bottom of the hole while ensuring a level head. Third, the sensor was inserted into the hole using a custom-built insertion tool (Figure 6). Care was taken during insertion to ensure that the sensor is properly seated at the desired depth and is thoroughly in contact with the hole. Following insertion and prior to backfilling, each sensor was checked by taking an initial reading and comparing it to the sensor calibration curve. Finally, the borehole was backfilled with native material from auger cutting and compacted with the tamping dowel (Figure 6).

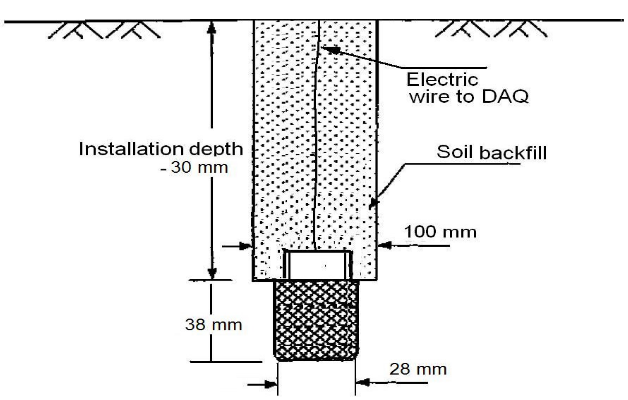


Figure 7: Installation of FTC-100

It is imperative that good soil to sensor contact be maintained to ensure the continuity of the water phase between the sensor and the soil thereby preventing erroneous results. To preclude the influence of air temperature on the sensor output, all of the signal cables were embedded underground at a depth of 0.4 m.

3.2.2 Jet Fill Tensiometer

Figure 8 illustrates the schematic diagram of the 2725ARl60 Jet Fill Tensiometer for measuring soil matric suction. The tensiometer consists of a plastic tube with a porous ceramic tip (25 mm round and 75 mm high). One tensiometer was installed in the park at a depth of 2.5 m.

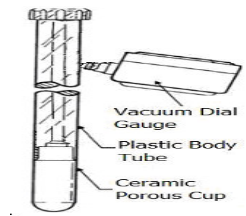


Figure 8: Schematic of jet fill tensiometer

Figure 9 describes the installation procedure for the jet fill Tensiometer. A 100 mm diameter borehole was drilled up to a 2.4 m depth using a hydraulic drilling machine. Using a 25 mm diameter coring tool, the hole was extended by another 100 mm to accommodate the ceramic tip of the tensiometer. The sensor head was saturated before the installation. The borehole was backfilled with native soil up to a height of about 500 mm and compacted. A 200 mm thick layer of bentonite-cement grout was applied to avoid any short-circuiting due to infiltration. The rest of the borehole space (1.7 m high and 100 mm diameter) was also backfilled with native soils and tamped to achieve a dry unit weight similar to that of the surrounding soils.

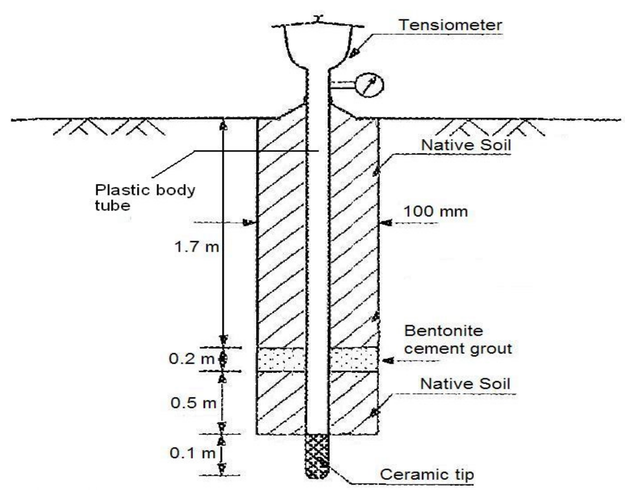


Figure 9: Installation of jet fill tensiometer

3.3 Soil Pressure

Figure 10 shows a photograph of the vibrating wire total pressure cell. The pressure cell is constructed from two circular stainless steel plates welded together (230 mm diameter). Manufacturer developed calibration curves were used to convert the measured frequency output to a pressure value. Two cells were installed at depths of 1.9 m and 2.3 m, respectively.

Figure 10: Photograph of the total pressure cell

Figure 11 summarizes the installation procedure for the total pressure cell. Based on the recommendations of Brackley and Sanders (1992), a well-designed installation procedure was adopted to minimize the effect of soil disturbance during excavation on the measurement of earth pressure. A 225 mm diameter hole was augured to a 120 mm depth above the proposed position of the centre of the pressure cell. Using a specially constructed cutting tool (Figure 12), a slot was made in the soil. The slot had a horizontal section identical to that of the pressure cell (6.3 mm thick and 230 mm round) and a base with a radius equal to the cell radius. The semi-circular surface was gently tamped thereby making a similarly shaped solid disc to ensure a good cell contact with the soil. A pre-determined amount of high strength glue was poured into the slot and the pressure cell was lowered into the hole. The displaced glue filled the slot up to about 50 mm above the top of the pressure cell. The cell was pushed to make contact with the bottom of the slot using rods. The rest of the borehole was backfilled with each layer tamped to achieve a dry unit weight closely matching the surrounding soil.

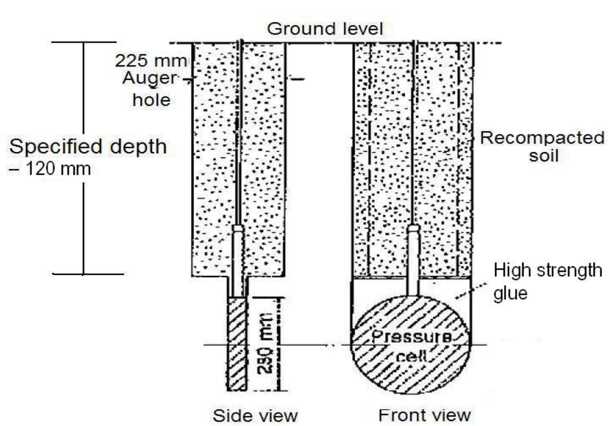


Figure 11: Installation of total pressure cell

Figure 12: Specialized cutting tools for pressure cell

Care was exercised to ensure an intimate contact between the cell and the bedding material. Localized or point loading of the cell by large aggregate or pebbles was avoided and disturbance in the field conditions was minimized.

3.4 Temperature

Figure 13 gives a typical 12.5 mm diameter thermocouple used to determine temperature in the field. A total of eight sensors were installed at two different locations with depths ranging from 0.4 m to 2.1 m at the two locations.

Figure 13: Photograph of the thermocouples

Figure 14 explains the sensor installation process for the thermocouples. Four thermocouples were attached to a 12.5 mm diameter and 2.0 m long wooden (wood is a bad conductor for heat) stick at prescribed depths by taping. An access hole of about 12.5 mm was drilled using a steel rod to a maximum depth of 2.1 m to accommodate the wooden stick. The wooden stick was inserted into the ground by pushing it through the hole. Care was exercised to ensure good thermal contact between the sensors and the soil.

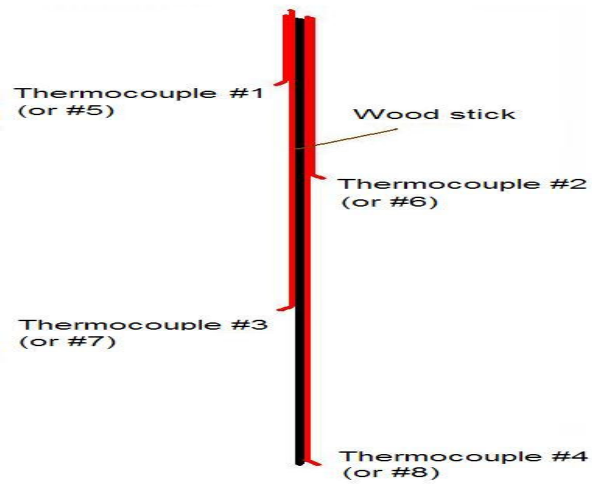


Figure 14: Installation of thermocouples

3.5 Displacement

Figure 15 shows survey markers used for this installation. Two lengths were used in this investigation, namely; 75 mm for the paved street and 400 mm for the park area. A total of thirty two survey markers (24 on the street and 8 in the park) were installed to monitor surface movement along the pipe and around the sensor installation areas. The survey markers were simply installed by pushing into the soil or pavement with a hammer.

Figure 15: Photograph of survey marker

4 SUMMARY AND CONCLUSIONS

To ensure the uninterrupted use of an engineered facility, it is essential to understand the *in situ* changes in soil conditions over time. A comprehensive instrumentation protocol was devised and successfully implemented to monitor the behaviour of AC water mains in the expansive Regina clay. The soil is known to undergo alternate volume changes due to seasonal variations in climatic conditions that govern water availability and temperature regime. To capture the soil response to such changes, five types of measurements were selected, namely: (i) water content through water content reflectometry probe; (ii) soil suction by thermal conductivity sensors and a jet fill tensiometer; (iii) soil pressure by total pressure cells; (iv) temperature by thermocouples; and (v) displacement by survey markers. Field installation of the various instruments was completed in May 2009 and all of the sensors are working properly to date. The data is being retrieved at regular intervals of time and thoroughly analyzed.

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