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Instrumentation of a Section of AC Pipe in Expansive Soil

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ABSTRACT

The City of Regina, SK, Canada, has been developed on a post-glacial lake deposit, called Regina Clay. The deposit is highly plastic, unsaturated, expansive clay that exhibits large volume changes as the soil water content changes. The water distribution system of the City of Regina has about 530 km of asbestos cement (AC) water mains. The rate of water main breakage has increased recently in old areas. A study was conducted by the National Research Council Canada, Center for Sustainable Infrastructure Research in Regina to investigate the causes of failures of the water mains.

Field instrumentation was successfully installed to monitor the performance of a replacement section of a 150 mm diameter AC water main in south Regina, where failures are frequent, to learn about soil behaviour and its interaction with this type of pipe. The instrumentation included sensors to measure pipe wall strains, *in situ* soil water content, soil movement, soil stress and temperature. Measurements were made in the pipe trench backfill and in the native soil around the backfill. This paper presents the first year monitoring data of the test section.

1. INTRODUCTION

The number of failures in the water distribution system in the City of Regina, SK, Canada, has increased greatly in recent years, primarily in older areas with asbestos cement (AC) pipes. Figure 1 shows the annual break rates of AC water mains from 1980 to 2004. During the ten year period from 1995 to 2004, the City had an average AC pipe breakage rate of 0.27 breaks/year/km, more than double the annual pipe breakage rate of 0.13 breaks/year/km of the period of 1985 to 1994. In previous research on the failure mechanisms that have caused the failure of the AC pipes, Hu and Hubble (2007) identified different factors that may have contributed to the failure of the AC pipes based on historical AC pipe break data, water quality data and the climate data in the City of Regina. These factors include pipe age, pipe diameter, climate, soil type, water quality and construction/maintenance methods. It was observed that all these factors had contributed to the failure of the AC water mains. However, the climate and local soil conditions were identified to be critical factors contributing to the failure.

The soil in Regina is a montmorillonite type clay soil (Regina Clay). This type of soil can undergo significant swelling when soil moisture increases and shrinkage when soil moisture decreases. The soil moisture content in this area may fluctuate significantly: the water content is commonly close to the plastic limit of 25% for the soil (Fredlund 1976). However, under extremely dry conditions, the water content can drop to less than 10% and, under extremely wet conditions, it can exceed 50% near ground surface. The high potential volume change, coupled with the local climatic conditions in Regina, indicates that the soil has the potential for considerable swelling or shrinking. The resulting changes in soil volume can induce differential soil movement that, in turn, can cause the development of stresses in buried AC pipes. In some cases, the stresses are believed to be of such magnitude that they cause the failure of pipes whose integrity may have already been compromised by other factors, such as chemical attacks from inside water and outside soils. Pipe breakage and its subsequent repair may affect water quality, interrupt traffic and business activities and consume already constrained infrastructure funding.

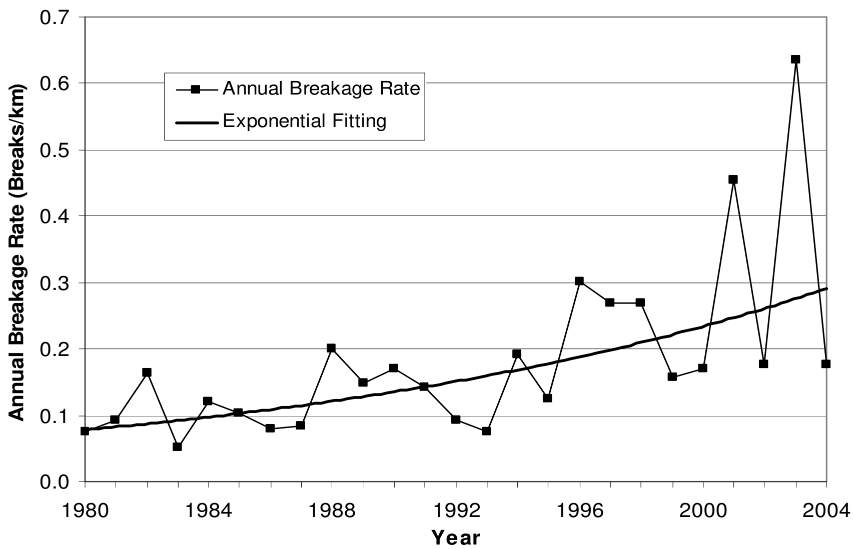

Figure 1. Annual break rates of AC water mains (1980~2004)

Considering the exponentially increasing AC water main breakage rate in Regina and its associated social, economic and environmental effects, the City is developing short-term operational and long-term renewal plans for the AC pipe asset to ensure that adequate resources (funds, manpower and equipment) are available to meet anticipated needs. An effective plan should use the full extent of the useful life of the individual pipes, while addressing issues of safety, reliability, water quality and economic efficiency. The full use of individual pipes requires an accurate understanding of how these factors lead to the deterioration and failure of the pipes.

To understand the working environments and the corresponding responses of pipes in expansive soils, field instrumentation was installed to monitor the performance of a section of water main in an expansive soil area of an older area of Regina where frequent pipe breakage has been observed in recent years. The instrumentation included sensors to measure pipe wall strains, *in situ* soil water content, soil movement, soil stress and temperature. Measurements were made in the pipe trench backfill and in the native soil around the backfill. This paper presents the first year monitoring data of the test section.

2. FIELD INSTALLATION

The test site was located at Cross Place in the Hillsdale area of south Regina. This location was selected because it is in an area with a high number of AC pipe breaks. It is located adjacent to a park to locate the instrumentation enclosure on public land and minimize cable length. Other factors, such as the site being relatively clear of utilities and minimal water service connections to minimize public inconvenience, were also considered.

Trench excavation & backfill

The field installation was carried out between September 11 and 15, 2006. A trench was excavated and the existing AC pipe section was removed. The trench was 2.5 m wide and 5.9 m long. The AC water main was 2.2 m below the ground surface, which is was within the typical burial depth (for the City of Regina) of 1.6 to 2.4 m. Installation of the instrumented section of pipe and other sensors was then carried out at different depths (levels) below the ground surface. The trench backfill was completed to the pavement base level and the first layer of pavement was placed right after the compaction of the final lift. The top layer of asphalt over the trench area was completed in the final day.

Sand provided by the City of Regina was used as backfill material for the haunch and bedding areas throughout the entire trench. The material used for backfill above the springline up to 150 mm above the top of the pipe was a material referred to as “mixed concrete”, which is a blend of recycled crushed concrete and subbase gravel with a ratio of 2:1 by weight. The “mixed concrete” was also used as subbase (approximately 170 mm thick) of asphalt pavement. The material used for backfill above the “mixed concrete” up to the subbase level was native soils excavated from the trench to simulate the working environment of adjacent AC pipes. The backfill was compacted with vibrating plate compactors.

Pipes

The pipe removed from the site was a 4 m long section of 150 mm diameter Class 150 AC pipe, originally installed in 1961. The new installed test section has the same size and the same class as the removed one.

Soil conditions

Four boreholes were drilled to the depth of 9.5 m. One borehole was located on the street, about 0.8 m south of the centreline of the pipe. The other three boreholes were located in the Park, approximately 2.0, 5.0, and 12.1 m away from the pipe, respectively (The boreholes were later used for the installation of rod extensometers and other sensors). The stratigraphy of the site consists of approximately 8.0 m of highly plastic clay, 1.5 m of silty clay and glacial till. Figure 2 shows the soil profile, index properties, and dry density at the borehole on the street.

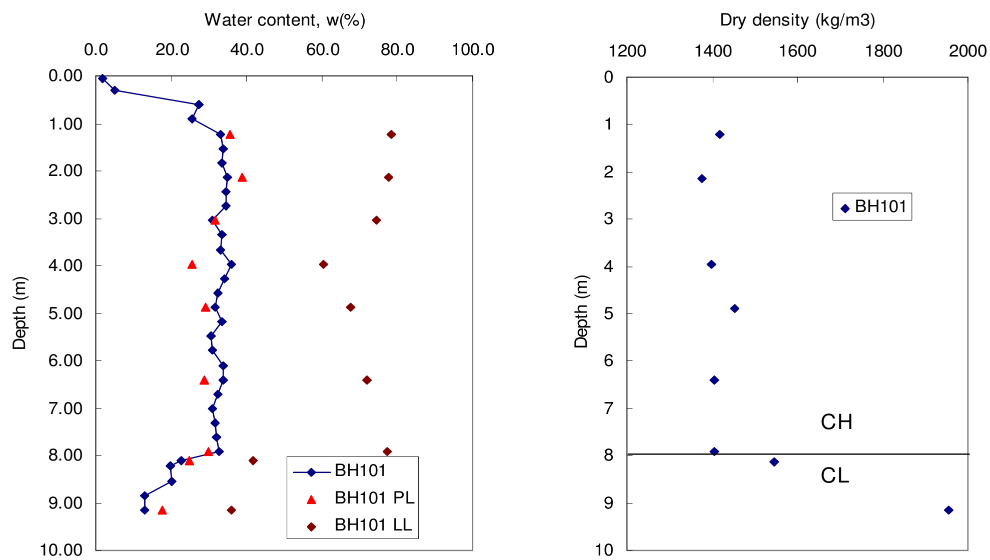

Figure 2. Soil profile, index properties, and dry density at the test site

The bedding and backfill materials used in this excavation were sampled for classification and laboratory testing. The moisture content and dry density were measured *in situ* using a Troxler 3400 Surface Density-Moisture Gauge every two lifts. Soil densities higher than 95% Standard Proctor Maximum Dry Density were generally achieved for all backfill lifts.

3. FIELD MONITORING SYSTEM

The typical section layout of the sensors that were installed for this project is shown in Fig. 3. Some soil suction sensors and amplitude domain reflectrometry probes (ADR) were installed at the same levels as those shown in this figure but in sections away from this section. The detailed layout of all sensors can be found in Hu *et al.* (2007b).

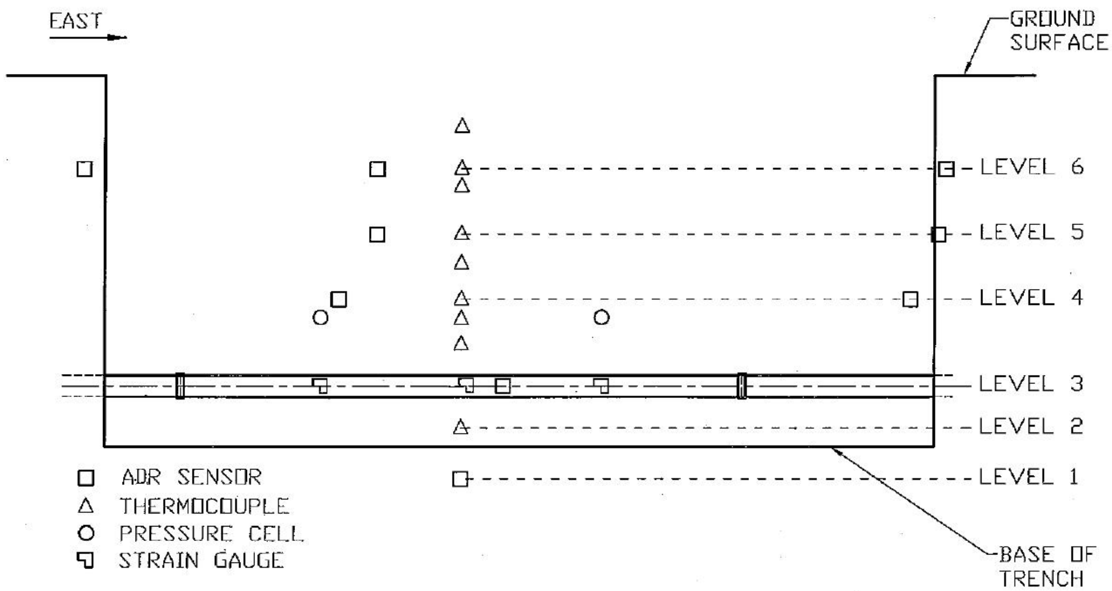

Figure 3. Schematic of sensor layout in typical section

These sensors included:

- Thermocouples for temperature monitoring on the exterior pipe surface, in the backfill and in the native soil,
- ADR probes for *in situ* soil moisture content monitoring,
- Rod extensometer to measure vertical soil movements at various depths in the park,
- Pressure cells for monitoring of vertical and horizontal soil stresses in the trench,
- Strain gauges to measure pipe deformation, and
- Other sensors for soil and water pressure, strains on the pipe surface, and vertical soil movements in the park and on the pavement surface.

More details on the installed instrumentation can be found in Hu *et al.* (2007b). The monitoring system was installed from September 12 to 15, 2006. The monitoring program would provide several years of continuous monitoring data as part of an on-going study.

4. RESULTS AND DISCUSSION

The following results are based on the data collected in the first year following installation, from September 15, 2006 to September 15, 2007.

Temperature

Figure 4 shows the average temperatures from representative levels (i.e., depths). It can be seen from this figure that, above the pipe level (Level 3), the closer to the ground surface, the more variable the temperatures; at and below the pipe level, temperature dropped at a fairly steady rate and has not gone below freezing. The deepest 0°C isotherm has reached about 1.6 m below the pavement surface around mid March for this period.

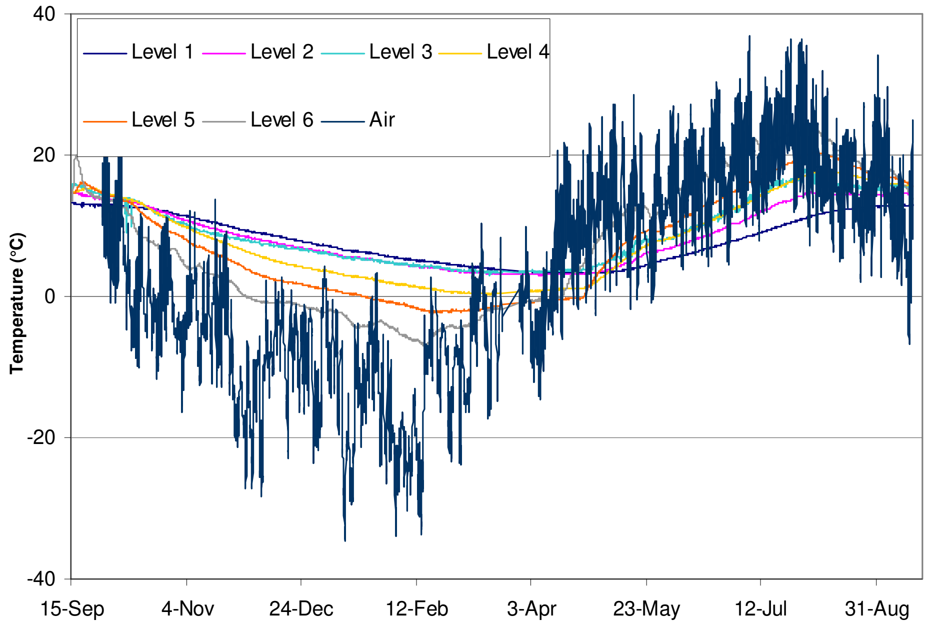

Figure 4. Temperature versus time at different levels in the trench

Precipitation

Figure 5 shows the precipitation for the one year period in the Regina area. The precipitation data are from the weather station in the Regina International Airport. The total precipitation for the one year period is 312.4 mm, below the normal annual precipitation of 388mm in this area. There are three precipitation peaks: one around early October 2006, one in May and the third in late July and early August. The total precipitation in the winter period (November 2006 to March 2007) was around 60 mm in the form of snow. The snow melt in early April plus the rainfall in May, as it can be seen in the following sections, may change the soil moisture conditions significantly. Although there were significant rainfalls around July and August, the soil water content may not be influenced or even reduced during this period, as this region is defined by a combination of large water deficit and relatively high temperatures (Hamilton, 1981).

Soil water contents

The volumetric water contents at different levels are shown in Fig. 6. This figure shows the water content measurements in the backfill only. The manufacturer-provided calibration curve for the clay soil was re-calibrated (Hu *et al.*, 2007a). A high number of soil water content variations can be observed. The shallower sensors provided more variable readings than the deeper sensors.

The sensor ADR1 was installed in Level 1 in the native soil under the trench bottom. The soil water content in the native soil increased slightly after installation in September until mid April and then decreased at a very slow rate.

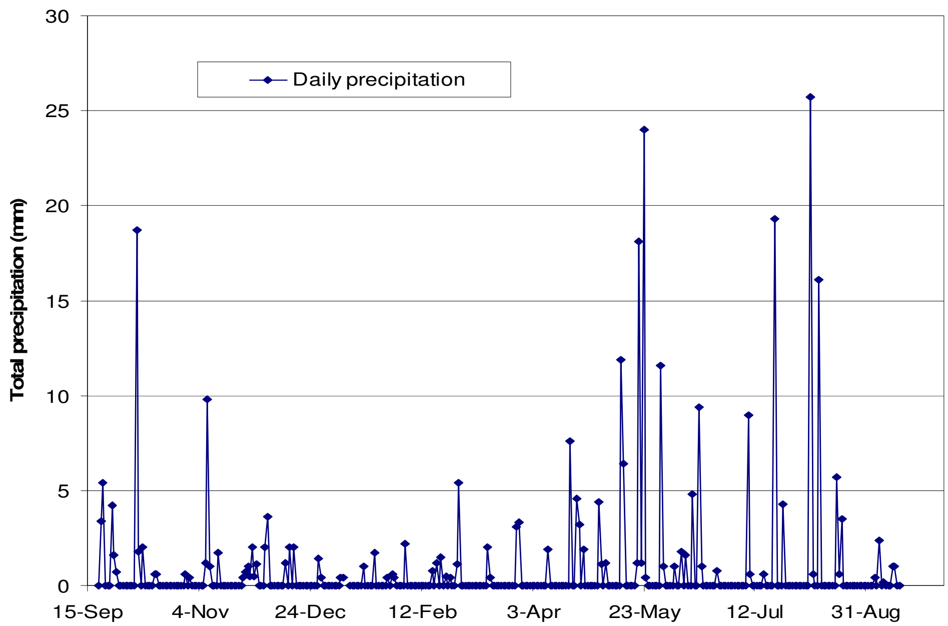

Figure 5. Precipitation for the one year period in the Regina area

The sensors in Level 2 (ADR2) and level 3 (ADR3) show similar change trend in water content, i.e., the water content increased significantly in the first stage, After that, the increase rate became much slow until early April, then the soil water content decreased steadily. The initial increase in water content of the sensors in these levels may be due to the water left in the trench when the old pipe was removed. The backfill in Levels 2 and 3 was sand and mixed concrete, respectively. The two backfills have high hydraulic conductivity rate, therefore, the extra water in the trench could reach the backfills rapidly and increased the water contents in these levels in a short period of time. After the initial period of increase, water content increase rate became slow due to the decrease in the amount of water available in the backfill.

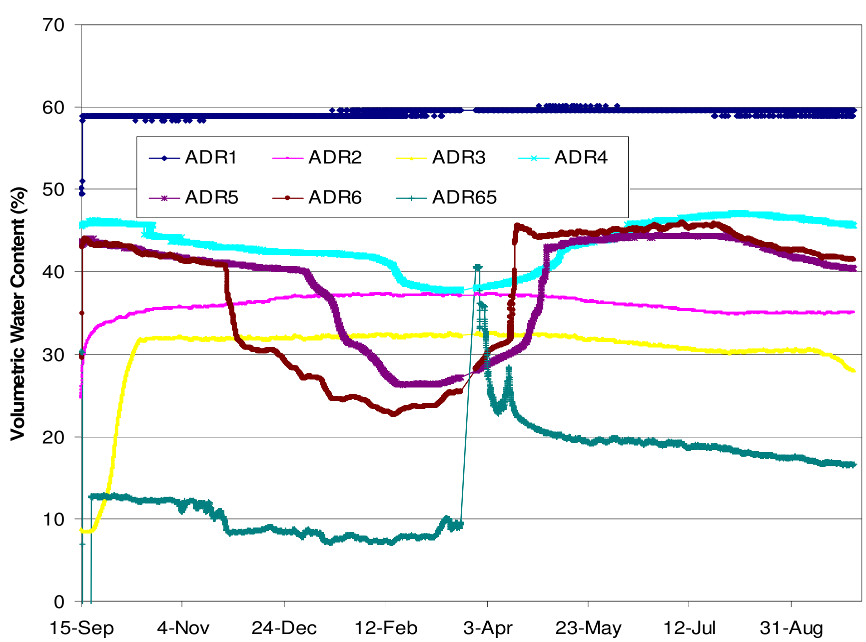

Figure 6. Volumetric water content versus time at different levels in the trench

ADR4, ADR5 and ADR6 were installed in the native backfill at Levels 4, 5 and 6, respectively. These sensors experienced similar water change trends, i.e., the water content decreases until the soil freezes. Then water content increases due to ice melts and rainfall in May until early August. The soil water content decreases gradually again, probably due to the kicking in of the dry summer effect. The sensors were not able to make meaningful readings when part or all of the moisture in the surrounding soils was frozen from the middle of November to the middle of April.

The sensor ADR65 was about 150 mm above Level 6, in the subbase layer of mixed concrete. The sensor indicated a decrease in water contents before freezing. After ice melt, the subbase layer experienced significant increase in water content while the water contents in the native layers below the subbase were relatively stable. The increase in water content in the subbase layer was due to the fact that when the arrival of spring, thawing occurs from the surface of the street downwards. Since the soil in the native layers beneath the subbase is still frozen, the increase in water contents brought about by thawing is not allowed to dissipate. With the further downward onto the native layers of the thawing, the sensor in the subbase experienced steady decrease in soil water content due to seepage to the native layers beneath it and the dry summer season as explained in previous section.

Soil movement

Figure 7 shows the ground movement at various depths in the park, 1.2 m away from the pipe. The rod extensometer used for the measurement is a 6 point rod extensometer with hydraulic anchors at different depths and, therefore, can measure the soil displacement at 6 depths, i.e., 0.6 (RD1), 1.2 (RD2), 2(RD3), 2.8 (RD4), 4.5 (RD5), and 8 m (RD6) below ground surface, respectively. A positive value of displacement indicates heave, while negative value indicate settlement. There was no data measured from early December 2006 to later March due to frozen ground. It can be noted from this figure that the soil movement was more pronounce near the ground surface. Some movement was recorded at 4.5 m depth (RD5) and the soil at 8 m depth (RD6) experienced little movement. There was significant soil movement in early April and early May around ground surface due to snow melt and rainfall, as explained in previous sections. After that, a steady soil settlement at all levels was observed until the end of the period analyzed. The biggest soil movement of 11 mm occurred near ground surface (RD1).

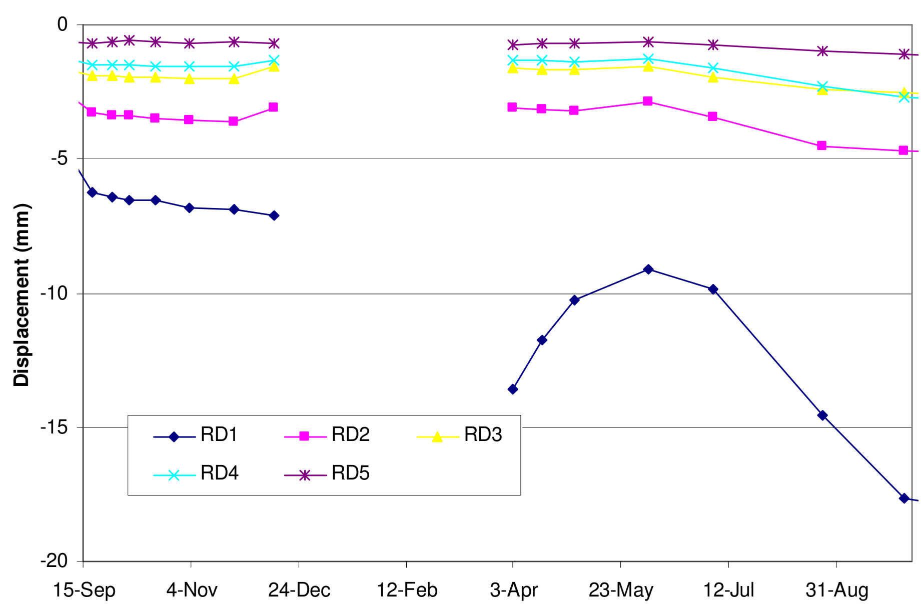

Figure 7. Vertical displacement versus time at different levels in the trench

Soil pressure

Figure 8 shows the earth pressures recorded by the pressure cells. The vertical and the horizontal soil pressure shows the same change trends, i.e., decreasing until early March and, then, increase until early August. The high soil pressures in August may be related to the dry soil conditions around August, which causes high soil suction. The pressure cells recorded negative soil pressures during part of the period for the vertical and all the period for the horizontal. This is not reasonable but no clear explanation is available at this time. One possible explanation is that the initial value was not recorded correctly.

Longitudinal strains

The longitudinal strains at the east end of the pipe are shown in Fig. 9. The longitudinal strains at the other two locations have a pattern similar to that shown in this figure and are not included here. It is noted that all strains are increasing steadily during this period, indicating that the soil consolidation is still going on. The trend is consistent with the steady soil movement at this level as observed in Fig.7. Also, the strains from the two springlines experienced changes bigger than the top and the bottom ones, suggesting that the pipe section is bearing higher loading from the horizontal direction than that from the vertical.

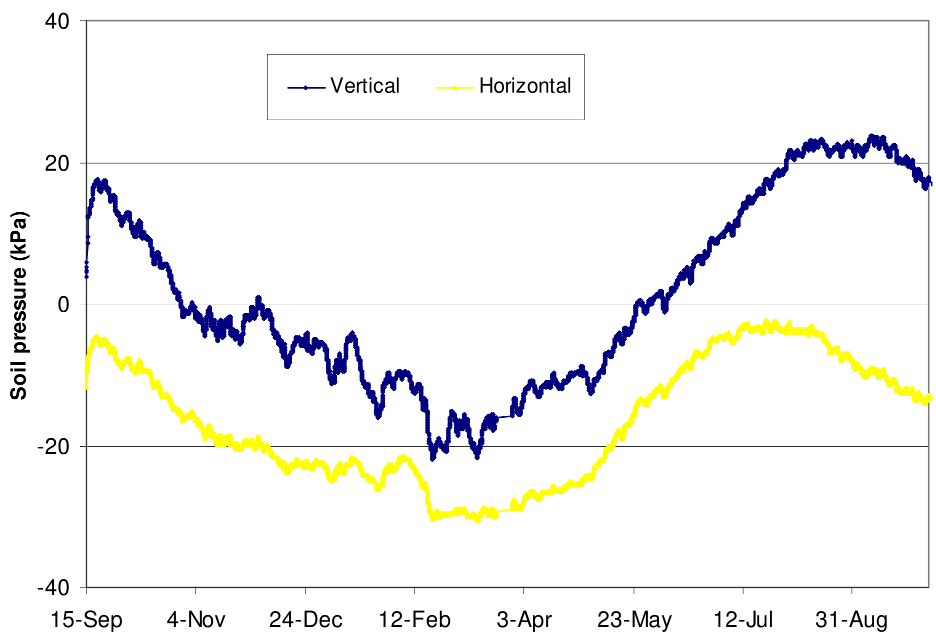

Figure 8. Horizontal and vertical pressures versus time at different levels in the north trench wall

Circumferential strains

Figures 10 shows the measured circumferential strains at the east end of the pipe section. The strains recorded at the other two locations have the same magnitude and similar change pattern. All the sensors recorded a sudden increase in tensile strain when the pipe was water pressurized at the 5th day of the construction (September 15, 2006). Also similar to the strains in the longitudinal direction, the strains in the circumferential direction also increased steadily.

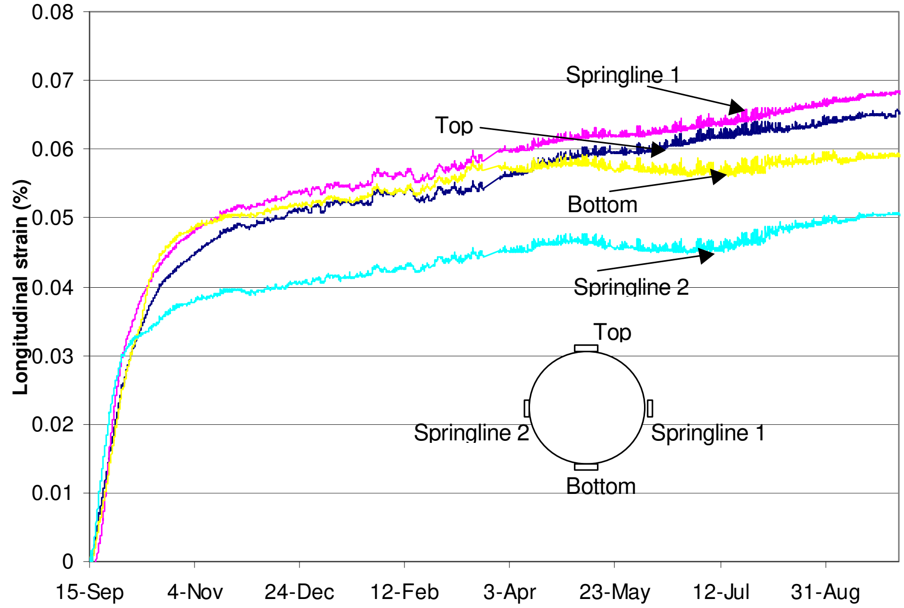

Figure 9. Longitudinal strains on the outside surface of the pipe section

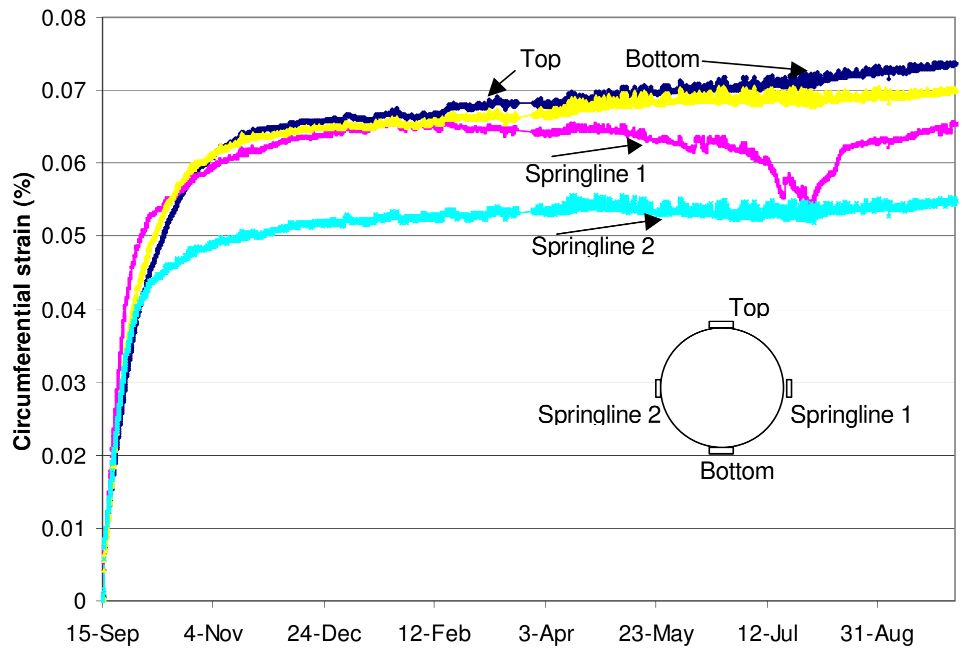

Figure 10. Circumferential strains on the outside surface of the pipe section

5. SUMMARY AND CONCLUSIONS

An instrumented AC pipe section was successfully installed to study the working environment and behaviour of a section of pipe in an area of Regina with a large inventory of AC water mains. This paper is a progress report on the research project on failure mechanisms of asbestos cement water mains in Regina, which is still under way. With future research, we hope to get further insight into the loads applied on the water mains. Further results of field monitoring and analysis will be reported in due course as the monitoring study proceeds.

The sensors installed included gauges for measuring strains in the pipe wall; pressure cells in the backfill soil near the pipe; thermocouples for soil temperatures; ADR for moisture content and displacement sensors for soil movement.

The data recorded in the first year of the monitoring program suggest that most sensors are working well and agree qualitatively with our knowledge of the pipe and soil behavior under the specific environmental setting. Soil water contents recorded by the amplitude domain reflectrometry sensors responded resonably well to changes in precipitation and temperature. Greater fluctuation between sensor readings was observed in sensors located near ground surface (thermocouples, ADR sensors, rod extensometers) due to the effects of local soil-atmosphere boundary conditions. Seasonal variation is evident in the recorded soil water contents, soil movement, and soil pressure.

The strains recorded by the strain gauges on the pipe surface suggest that backfill soil has not yet been stabilized after one year from installation.

6. ACKNOWLEDGEMENTS

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