# Monitoring cyclic strain below a railway embankment overlying a peaty foundation using novel instrumentation

Michael Hendry
*Department of Civil and Geological Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada*
Derek Martin
*Department Geotechnical Engineering– University of Alberta, Edmonton, Alberta, Canada*
Lee Barbour
*Department of Civil and Geological Engineering – University of Saskatchewan, Saskatoon, Saskatchewan, Canada*
Tom Edwards
*Canadian National Railway, Edmonton, Alberta, Canada*

ABSTRACT
The CN mainline railway track through Alberta runs east-west passing through Edmonton and Edson. Just east of Edson the mainline embankment runs over a soft peat formation. The rail and concrete-tie structure as well as the embankment which pass over the peaty ground have required increased maintenance to ensure serviceability. In 1998 a section of this embankment was remediated by installing timber piles under both ends of every second tie.

CN has recently been replacing concrete ties at similar sites with larger timber ties. This tie replacement has met with some success in reducing the wear on the ties and will be used on a section of this peat mire crossing which was not strengthened with timber piles in order to compare the relative performance of these two means of remediation.

This paper details a study carried out to measure the deformation of the railway embankment under normal freight train loading, both before and after the tie replacement. These measurements were conducted with both conventional geotechnical instrumentation and motion capture instrumentation adapted from computer generated film applications (SAA). The purpose of this instrumentation is to characterize the effect of the tie replacement and timber piles on the deformation concentrations within the embankment and peaty foundation material.

RÉSUMÉ
La voie ferrée principale CN qui traverse l'Alberta se dirige d'est en ouest en passant par Edmonton et Edson. Juste à l'est d'Edson le remblai de la voie ferrée repose sur une formation de tourbe molle. Le rail, les traverses en béton ainsi que le remblai qui repose sur la terre tourbeuse ont exigé une maintenance accrue afin de garantir une aptitude au service. En 1998 une section de ce remblai a été corrigée en installant des pieux en bois sous les deux extrémités de chaque deuxième traverse.

CN s'est récemment lancé dans le remplacement des traverses en béton dans des sites semblables avec des traverses de bois plus grandes. Ce remplacement de traverses a eu un certain succès en réduisant l'usure des traverses et sera utilisé sur une section de cette traversée de bourbier de tourbe qui n'a pas été renforcée avec des pieux en bois afin de comparer la performance relative de ces deux moyens de remédiation.

Cet article présente les détails d'une étude réalisée pour mesurer la déformation du remblai de chemin de fer dans des conditions de chargement normale de train en marchandises, aussi bien avant qu'après le remplacement des traverses. Ces mesures ont été accomplies grâce à la combinaison d'une instrumentation géotechnique conventionnelle et d'une instrumentation de capture de mouvement adaptée à partir de films générées par l'ordinateur (SAA). Le but de cette instrumentation est de caractériser l'effet du remplacement des traverses et des pieux en bois sur les concentrations de déformation dans le remblai ainsi que dans la matière tourbeuse de la fondation.

## 1 INTRODUCTION

Railway embankments over peat foundations are difficult to build and maintain. Many of the existing embankments were constructed when train loads, lengths and speed were smaller than presently used today. Large cyclic strains are produced within the peat due to train loading. The large concentrated loads associated with trains on railway embankments are particularly destructive to rails and concrete-tie structures due to the wear produced by large cyclic movements of the embankment and foundation.

The purpose of this study was to determine the distribution of strain within the embankment and underlying peat before and after the replacement of the concrete-ties with timber-ties in order to identify the mechanism responsible for improved performance. This was to be accomplished by measuring the deformation of the railway embankment under cyclic train loading, using extensometers and measuring induced pore-water pressures using strain-gauge piezometers. These measurements were conducted with both conventional geotechnical instrumentation and motion capture instrumentation adapted from computer generated film applications. The purpose of this instrumentation is to characterize the effect of the tie replacement and timber piles on the deformation concentrations within the embankment and peaty foundation material

The scope of this paper is to present the monitoring system and preliminary monitoring results from the site prior to remediation. The result and interpretation of the results as presented in this paper are preliminary as detailed analyses are ongoing.

## 2 DESCRIPTION OF SITE

The CN mainline railway track runs east-west through Alberta passing through Lloydminster, Edmonton, Edson and Jasper (Figure 1). East of Edson the mainline runs over an over a peat mire formation between miles 101.4 and 102.6 (Figure 2) on the Edson subdivision. It is this embankment and underlying peat which is the focus of this study.

The embankment was initially constructed in the 1920s, using a timber raft construction (MacFarlane 1969). The embankment ranges from 1.6 to 2.0 m above the local terrain.

### 2.1 Description of Problem

The rail and concrete-tie structure as well as the embankment require increased maintenance to ensure serviceability. Large movements of the rail-track structure have caused the concrete ties undergo increased wear as they are pushed and rolled through the ballast. The ties often become skewed, broken, or wear out prematurely. The result of this wear is a rounding the underside of the concrete ties eventually exposing steel reinforcement (Figure 3), and rail seat abrasion (the sawing of the rail through the tie).

These large movements are identified by the presence of polish on the rails due to the movement of the rails with respect to the ties ("running rail") (Figure 4).

### 2.2 Previous Work on Site

Remediation work was undertaken at this site in 1998 between miles 102.2 and the western edge of the mire. In order to reduce the movements of the embankment. The remediation consisted of timber piles driven under both sides of every second tie down through the peat, and approximately 1 m into the underlying competent material. This remediation appeared to be successful with reduced wear of the rail and concrete-ties and reduced maintenance of the ballast.

Gravel berms were built along each side of the embankment from miles 101.4 and the western edge of the peat bog to provide equipment access. This also resulted in shoulders of up to 10 m wide along this section of the embankment.

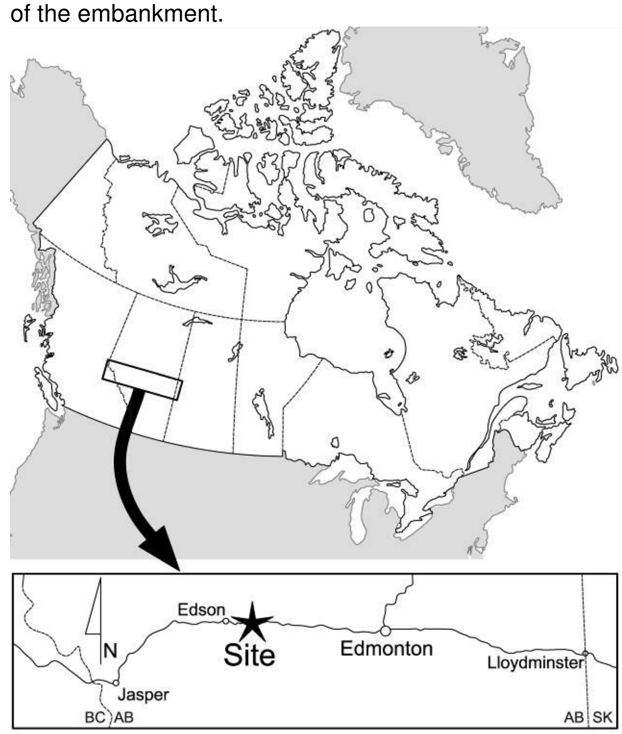


Figure 1. Location of site.

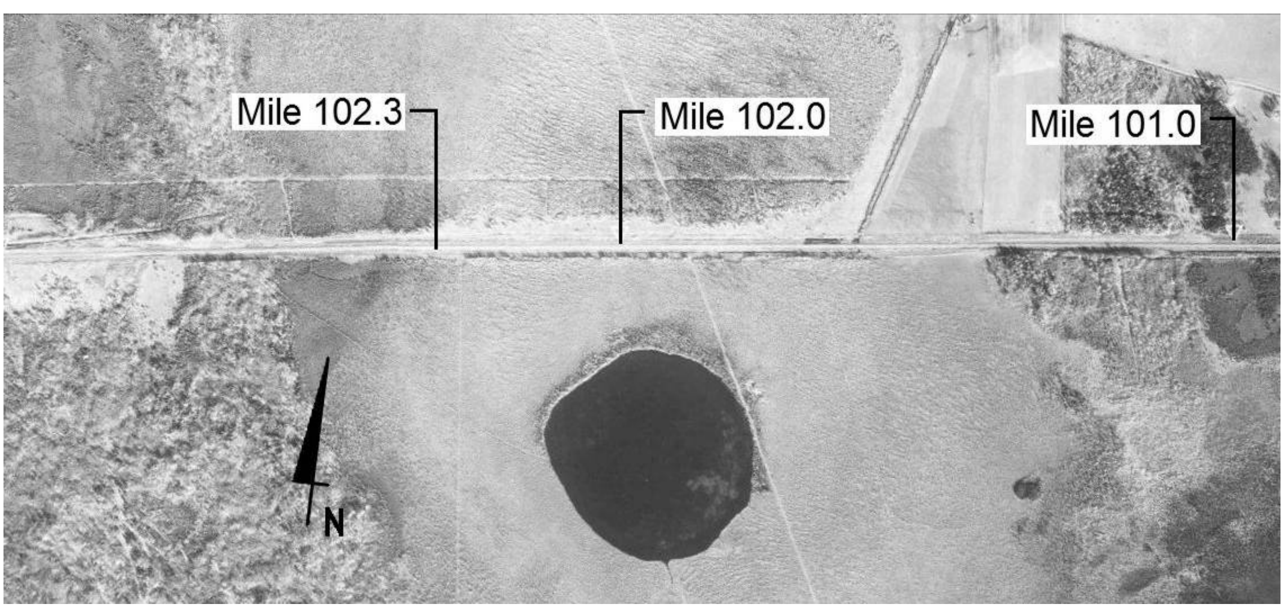


Figure 2. Arial photograph of peat bog crossing, location of instrumentation sites shown.

Figure 3. Picture of the worn underside of concrete-tie. This tie is a typical example of the ties removed from between mile 101.4 and 102.1 in October 2007.

## 2.3 Sub-sites

Two locations on the embankment were selected for in-depth investigation and instrumentation (Figure 2). The first location is at mile 102.0, a section that is currently experiencing the largest deflections and rate of deterioration. The second location is at mile 102.3. This location was within the section remediated in 1998 and was selected to measure the effectiveness of remediation with timber piles.

# 3 INVESTIGATION AND INSTRUMENTATION

The following section describes the ground investigation conducted at the site along with the instrumentation installed in the embankment.

## 3.1 Ground Investigation

The purpose of the ground investigation was to determine the construction and composition of the embankment, and to allow for the installation of the instrumentation. A total of sixteen boreholes were drilled with a hollow stem auger. Descriptive logs were taken for each borehole. Several disturbed and Shelby tube samples were also taken for future laboratory testing.

A GPS survey of the whole site was conducted to provide cross-sections of the embankment.

## 3.2 Instrumentation

The purpose of the instrumentation was to determine the distribution of strain within the embankment and underlying peat. The differences in these strains between the section remediated with timber piles and the unremediated section were of particular interest. The instrumentation consisted of conventional instruments as well as a motion capture system.

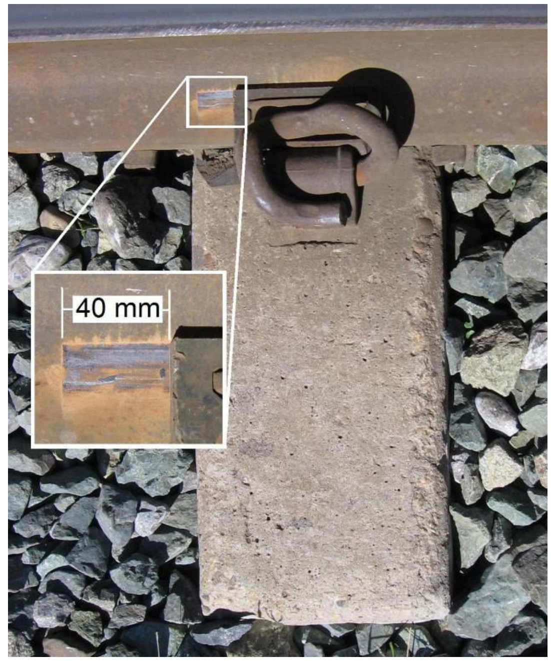


Figure 4. Picture of polish on rail from clips. This is used as an indicator of running rail.

### 3.2.1 Conventional Instrumentation

The conventional instrumentation consisted of strain-gauge piezometers and extensometers (constructed by RST instruments). Both types of instruments are capable of reading at a rate of up to 90 Hz.

Three piezometers were installed under the centreline of the track at the mile 102.0 site, at depths of 6.4 m, 4.4 m and 2.8 m. The piezometers were pushed into the soil through the hollow stem auger, and back filled with spoil and a bentonite plug placed at the base of corduroy.

The three extensometers were also installed at the mile 102.0 site. These were located about 0.6 m off the north end of the railway ties. The anchors of the extensometers were installed at depths of 7.46 m, 5.46 m and 3.46 m. The hole was drilled to a depth slightly exceeding the target depth and sand was used to fill the hole to the selected depth. The anchor was then placed in the hole and approximately 0.43 m of sand was poured in around the anchor to secure the anchor. The borehole for extensometer anchored at a depth of 5.46 m began to collapse before the installation of the anchor. The anchor was pushed to the proper depth with a PVC tube, thus no sand was placed beneath the anchor.

The instrumentation at the mile 102.3 site consisted of two strain-gauge piezometers installed under the centreline of the track, at depths of 1.9 m and 4.4 m. The purpose of the piezometers at mile 102.3 was to determine the effectiveness of the transfer of the train load to the pile instead of the soft foundation.

3.2.2 Motion Capture Instrument

The motion capture system consisted of a research-grade ShapeAccelArray (SAA). The SAA was a MEMS-based deformation monitoring system manufactured by Measurand Inc. The SAA consisted of 30 cm (1 foot) rigid segments connected by a two degree of freedom joint which allows the joint to bend but not twist (Figure 5). The resulting data was a 3D shape of a borehole at 30 cm intervals (Abdoun and Bennett 2008). The research-grade SAA is capable of reading at a rate of up to 120 Hz, though an internal analog low-pass filter on the individual MEMS had an upper frequency of only 20 Hz.

In this application the motion capture instrumentation was used to measure the horizontal deformation of the embankment and peat under cyclic train loading.

Typically the SAA is used to measure long-term deformation, averaging many readings to obtain a horizontal displacement. In this case, readings are required in real time and therefore averaging was not possible. Initial laboratory testing of the array under cyclic loading has been conducted. The testing compared the SAA readings of a single joint subjected to cyclical motion to the readings of a LVDT measuring the motion of the joint. The SAA produces results of similar magnitude under cyclical movements and correctly measures trends for displacements that follow a sine function at 1 Hz (Fig. 6). The recorded higher frequency, lower magnitude motions may be due to vibrations of the testing equipment, or the annular space in the PVC tube between the walls and the SAA.

Figure 5. SAA on spool (104 m array shown) (Abdoun and Bennett 2008).

The field installation for the SAA utilized a 27 mm I.D. PVC conduit installed in a borehole about 0.6 m off the north end of the concrete-ties at the mile 102.0 site during the ground investigation. The base of the conduit was installed at a depth of 5.2 m.

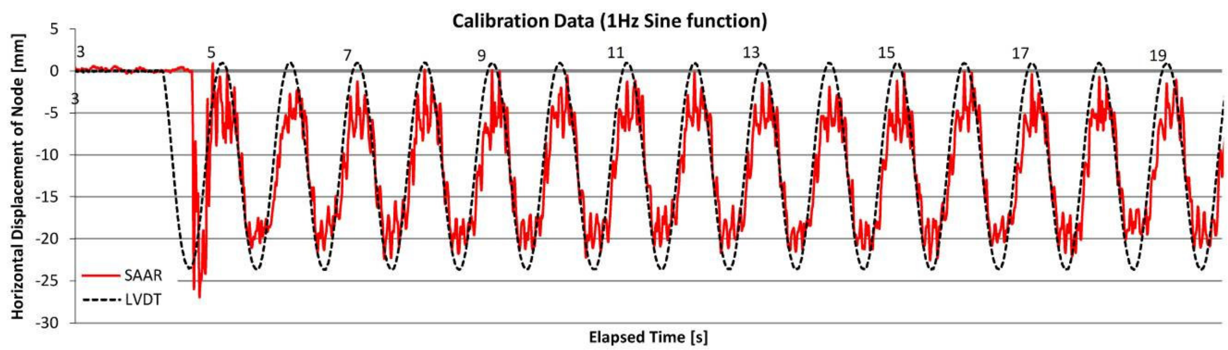


Figure 6. Results of initial calibration tests of SAA in laboratory. Comparison of measurements from SAA and LVDT.

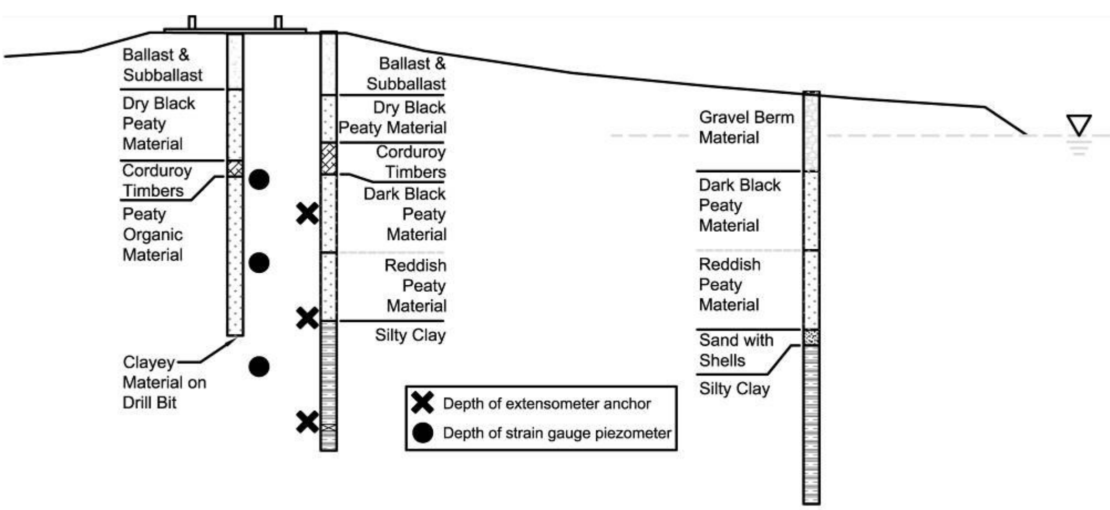


Figure 7. Resulting boreholes, embankment profile and depth of installed instrumentation at mile 102.0

## 4 PRESENTATION OF RESULTS

### 4.1 Ground Investigation

The borehole logs and surveyed cross-section of the embankment are combined in Figure 7 to illustrate the composition of the embankment and depth of the underlying peat. The embankment at mile 102.0 consists of ballast and sub-ballast to a depth of 1.2 m. Below this is a 1.0 m layer of peaty organic material, the timber corduroy log raft, 2.9 m of peat and an underlying silty-clay. The corduroy was found to be in good condition in that the auger had difficulty boring through it and retrieved pieces of the logs looked well preserved.

The boreholes in the remediated section at mile 102.3 site yielded similar results. A pile was hit with the auger at this location which suggests that the pile (and possibly the other piles) had moved out from under the ties and now sat about 0.3 to 0.6 m out from the end of the tie.

### 4.2 Data from instrumentation

The data sets shown below were obtained during a single train crossing. The train was a relatively heavy freight train loaded with grain and traveling west. Due to work being conducted on the railway line the train speed was restricted to 40 km/h. The results are typical of the data obtained from numerous trains which crossed the instrumented sections that day.

#### 4.2.1 Conventional Instrumentation

The three piezometers at mile 102.0 site were installed at depths of 6.4 m, 4.4 m and 2.8 m. These depths were into the silty-clay, approximately mid-way through the peat, and just below the corduroy respectively (Figure 7). The three extensometers with the anchors at depths of 7.46 m, 5.46 m and 3.46 m were installed well into the underlying silty-clay, just above the interface between the peat and silty-clay and approximately 0.6 m below the corduroy respectively (Figure 7). The two strain-gauge piezometers at mile 102.3 were installed at depths 1.9 m and 4.4 m, both within the peat layer.

The extensometer data is presented in Figure 9. Only the deepest (7.46 m) and the shallowest (3.46 m) extensometers were working that day. The overall deflection of the embankment reached 10.5 mm. Of this deflection, 7.5 mm was cyclical in nature and occurred during the passage of each pair of bogies (front and back of cars). Up to 3 mm of the overall deflection was residual deflection which remained between the application of cyclic bogie loads and after the passage of the train. The residual deflection immediately reduced to 1.2 mm after the train passed and decreased to 0.5 mm prior to the arrival of the next train 13 minutes later.

Almost half of the cyclical deflection and most of the residual deflection occurred within the embankment and the upper 0.6 m of peat.

The strain-gauge piezometers installed at mile 102.0 showed a significant increase in the pore-water pressure due to the train loading. The excess pore-water pressure, from the two piezometers in the peat, reached maximum values after only the passage of the locomotives and a few cars. The excess pore-water pressure in the peat then fell towards zero shortly after the passage of the train. The excess pore-water pressure in the silty-clay reached a maximum shortly after the passage of the locomotives and steadily declined during the passage of the train. After the passage of the train the excess pore-water pressure dropped to a negative value before recovering to zero.

The strain-gauge piezometers installed at mile 102.3 show only a minor increase of pore-water pressure due to the train loading.

#### 4.2.2 Motion Capture Instruments

The data resulting from the SAA consisted of 3D position, and change in position of the individual joints of the array referenced to the base of the borehole. The horizontal motion of the embankment and peat were resolved in two directions; perpendicular to the rail (deflections away from the rail were positive indicative of expansion of the embankment) and parallel to the rail (motion in the direction of train travel, time 0, as positive). A segment of the resulting horizontal displacement from the passage of three bogie pairs is shown in Figure 11.

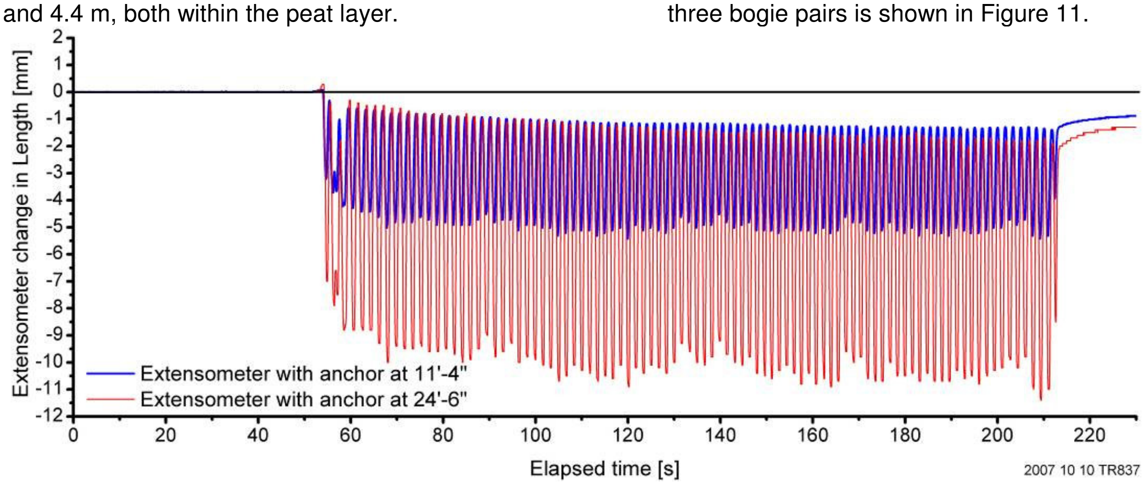


Figure 8. Extensometer measurements at mile 102.0 during the passage of a grain train.

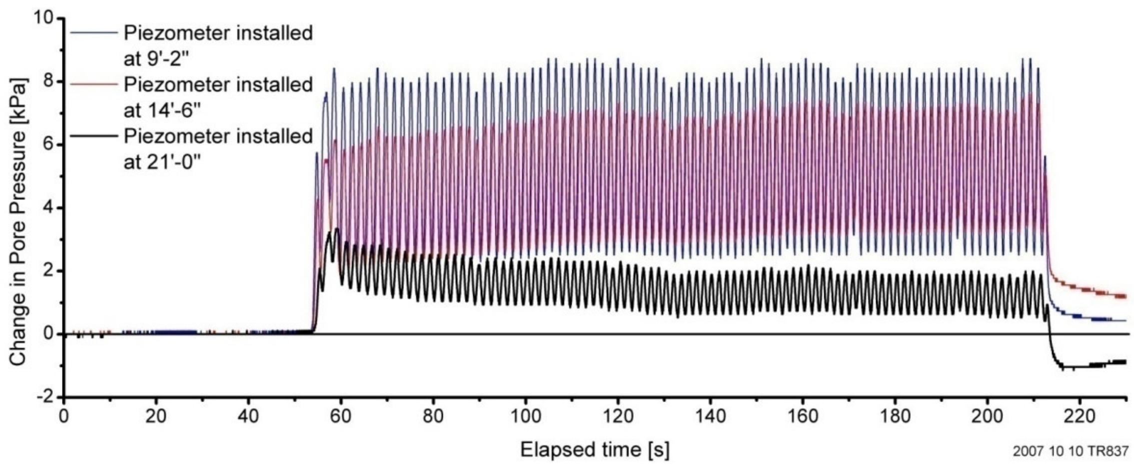


Figure 9. Strain-gauge piezometers measurements at mile 102.0 during the passage of a grain train.

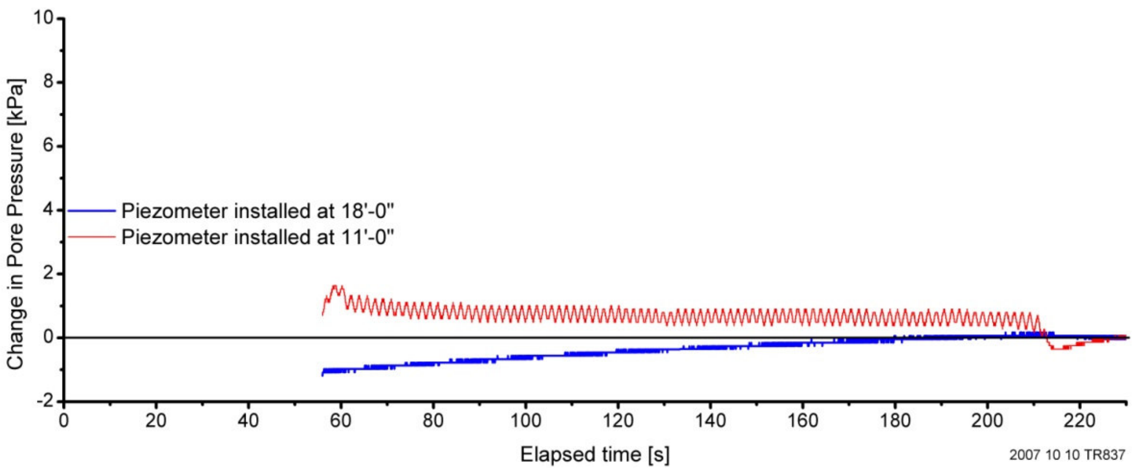


Figure 10. Strain-gauge piezometers measurements at mile 102.3 during the passage of a grain train.

The horizontal maximum horizontal deflections in both the perpendicular and parallel directions reach a magnitude of +12 to -12 mm.

Most of the deflection is located above the corduroy in the embankment, with a noticeable change in the pattern of deformation coinciding with the depth of the corduroy, especially in the parallel direction.

The deflection of three SAA joints are the horizontal plane is plotted in Figure 12. This motion clearly shows a difference between the response of the structure to the lead bogie versus the trailing bogie, and the three-dimensional nature of this response.

## 5 DISCUSSION

To determine the distribution of strain within the structure the vertical strains were calculated over the length of the shallowest extensometer, and between the anchors of the shallowest and deepest extensometers. The results are presented in Figure 13. From this it is evident that both the embankment and underlying materials have residual strain which is somewhat greater extent in the embankment. The deeper strains are negative (expansive) between cyclic loads. The speed at which the train is travelling does suggest these are due to dynamic excitation (Hendry 2007).

A comparison of the piezometer reading from mile 102.0 and 103.3 show the effectiveness of the piles. The large difference in the pore-water pressures from under train loading at mile 102.3 compared to those at mile 102.0 indicate that the majority of the load is transferred through the piles to the underlying silty-clay material.

The data sets from the SAA (both perpendicular and parallel to the rails) show the distribution of horizontal deformation and thus strain within the structure. The greatest deformations occur within the embankment. The effect of the corduroy is apparent as large reductions in horizontal deformation coincide with the depth of the corduroy, acting to confine the largest deformations to above the embankment. Negative values in deformation perpendicular to the rails (Figure 11a) requires further explanation as these represent a horizontal contraction of the embankment.

The horizontal deformation perpendicular the rails show an unexpectedly high horizontal deformation both in front and behind the bogies (Figure 11b). The similarity of the magnitude of horizontal deflection in both the parallel and perpendicular directions and the complex distribution of strain means this is a truly three-dimensional problem and two-dimensional analysis will be inadequate.

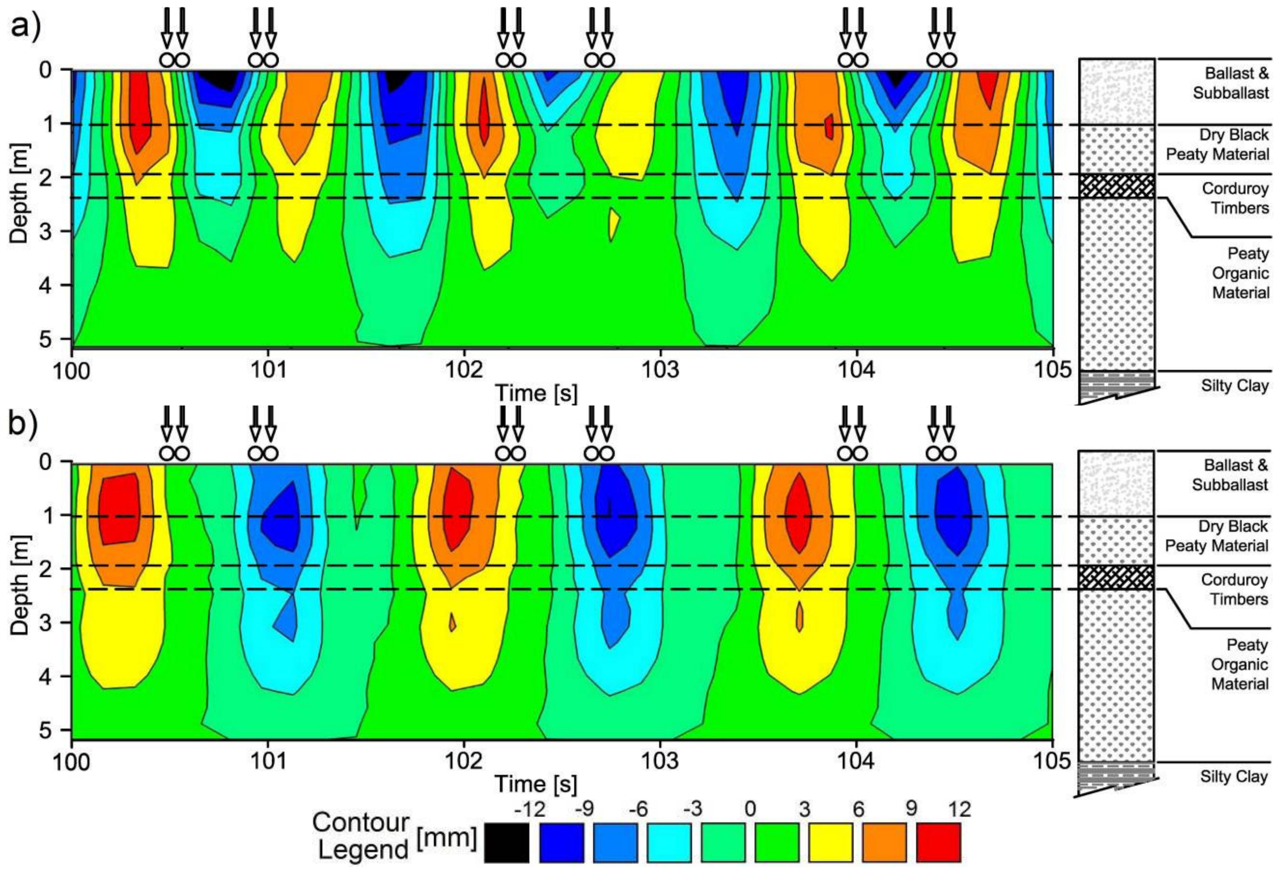


Figure 11. Resulting data from SAA measurements for a) The horizontal deflection perpendicular to the rails. b) The horizontal deflection parallel to the rails. Positive deflection is either away from the rail (horizontal expansion) or in the direction of train travel (to the left of page).

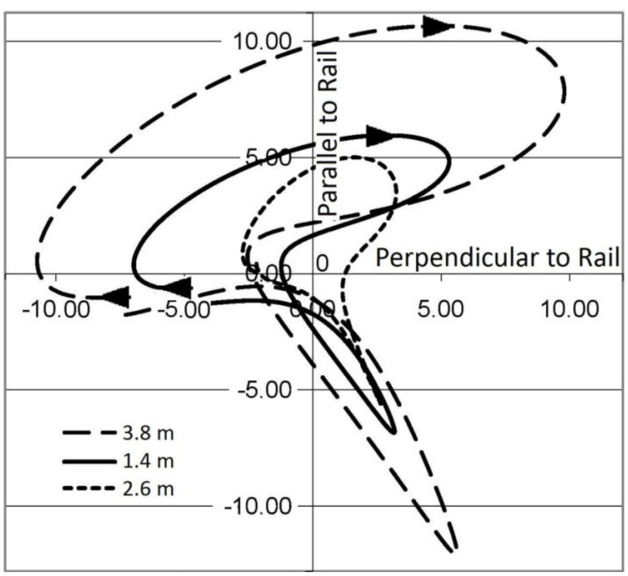


Figure 12. Resulting path of three SAA joints in the horizontal plane due to the passage of a pair of bogies (time 101.5 to 103.3).

## 6 CONCLUSIONS

The instrumentation of the railway embankment has provided insight into the distribution of strain and the change in pore-water pressure within the embankment and its foundation. The difference between the increase in pore-water pressure at mile 102.0 and mile 102.3 clearly show the effectiveness of the piles at transmitting the load to the underlying silty-clay.

The project will continue to use the SAA for the measurement of horizontal deformation of railway embankments and their underlying foundation; and to determine the effects of the replacement of concrete ties on the distribution of strain.

## ACKNOWLEDGEMENTS

The writers would like to acknowledge the contribution of Canadian National Railways for providing both the project and funding. This research was made possible through the Railway Ground Hazard Research Program, funded by the Natural Sciences and Engineering Research Council of Canada (NSERC), CP Rail, CN, and Transport Canada.

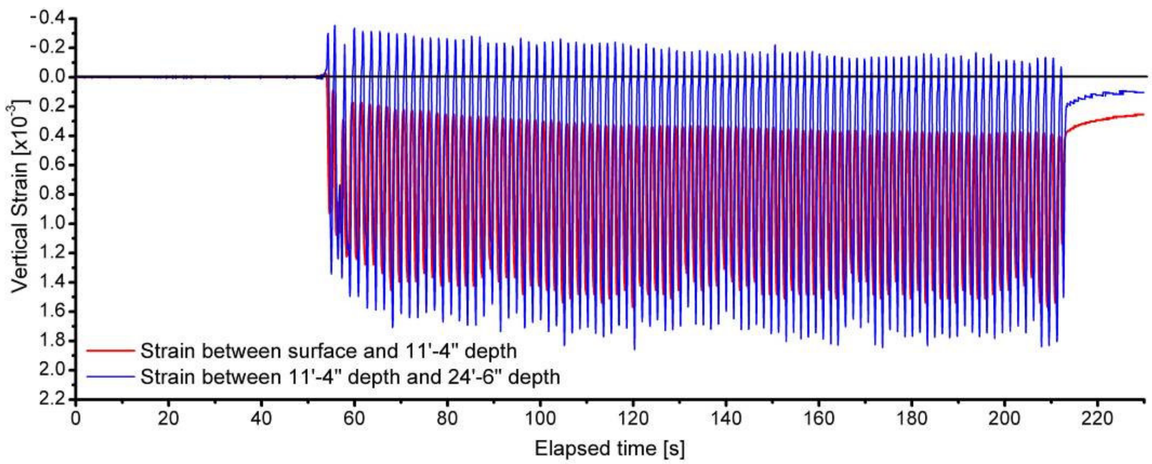


Figure 13. Strain over length of shallowest extensometer and between the anchors of the shallowest and deepest extensometers from measurements at mile 102.0 during the passage of train.

The writers would also like to acknowledge Lee Danish and Measurand Inc. for providing assistance in installation and development of a SAA system to meet the needs of this study.

REFERENCES

Abdoun, T., and Bennett, V. 2008. A New Wireless MEMS-Based System for Real-Time Deformation Monitoring. Geotechnical News, 26(1): 36-40.

Hendry, M. 2007. Measurement and Analysis of the Train-induced Dynamic Response of Railway Track and Embankments Constructed over Soft Peaty Foundations. MSc. Thesis, University of Saskatchewan, Saskatoon.

MacFarlane, I.C. 1969. Engineering Characteristics of Peat. In Muskeg Engineering Handbook. University of Toronto Press, Toronto. pp. 78-126.

Sellers, J.B., and Taylor, R. 2008. MEMS Basics. Geotechnical News, 26(1): 32-33.