Laboratory Measurement of the Load Reduction on Buried Structures overlain by EPS Geofoam

M. Raafat Ahmed & Mohamed Meguid
Civil Engineering and Applied Mechanics, McGill University, Montreal, Quebec, Canada
Jim Whalen, P.Eng.
Plasti-Fab Ltd , Calgary, Alberta, Canada

ABSTRACT
In this study a laboratory setup that has been designed and built to measure the changes in earth pressure acting on a rigid pipe installed using the induced trench method is described. A layer of EPS geofoam embedded within the backfill soil above the pipe is used as a compressible material to promote positive arching. A series of experiments has been conducted by loading the surface of the backfill soil with a strip load parallel to the pipe axis under both static and cyclic conditions. The earth pressure distribution acting on the pipe is measured using a flexible sensing technology. Sheets containing arrays of flexible sensors were wrapped around the pipe wall and connected to a data acquisition system. By comparing the measured pressures with benchmark experiments conducted without geofoam installation, it was found that placing the EPS layer has reduced the vertical earth pressure above and below the pipe under both static and cyclic loading conditions.

RÉSUMÉ
Dans cette étude, un montage de laboratoire, qui a été conçu et construit pour mesurer les changements dans la poussée des terres agissant sur une conduite rigide installée en utilisant la méthode de la tranchée induite, est décrit. Une couche d'EPS geofoam, incorporé dans le sol de remblai au-dessus de la conduite, est utilisée comme un matériau compressible pour produire un effet de voute positif. Une série d'expériences a été réalisée en appliquant une charge sur la surface du sol de remblai sous forme d'une bande de chargement parallèle à l'axe de la conduite dans les conditions statiques et cycliques. La distribution de la poussée des terres agissant sur la conduite est mesurée en utilisant la technologie de détection tactile. Des réseaux de capteurs flexibles ont été enroulés autour de la paroi du tube et reliés à un système d'acquisition de données. En comparant les pressions mesurées avec des expériences de référence menée sans installation de Geofoam, il a été constaté que placer la couche d'EPS a réduit les pressions verticales du sol au-dessus et en dessous de la conduite sous un chargement statique et cyclique.

1 INTRODUCTION

The induced trenching method, also known as the imperfect ditch, is a construction technique used for pipes and culverts under high embankments. In contrast to positive projecting method (see Figure 1) a compressible layer is introduced above the buried structure to reduce the vertical stresses transferred to the walls of the structure. This is generally attributed to the mobilization of shear stresses in the upward direction above the boundaries of the compressible layer leading to a reduced net pressure on the pipe.
Larsen (1962) studied the induced trench design of culverts using baled straw as compressible material and compared the measured pressures with similar culverts built using the positive projecting method. The layer of baled straw was placed directly on the pipe such that the central prism of soil above the conduit would settle more than the adjacent soil. Favorable results were obtained for the two investigated concrete pipes with diametrs of 54-in. and 66-in supporting 38-ft to 65-ft of fill height. Performance of the pipes was evaluated by measuring their distortion. Lefebvre et al., (1975) used induced trenching to construct a 15.5m span flexible culvert with backfill of 13.4m in height. The structure, shown in Figure 2, was spanning over the Vieux Comptoir River, 800 km North of Montreal. Positive arching was achieved by providing a compressible zone inside the footing.

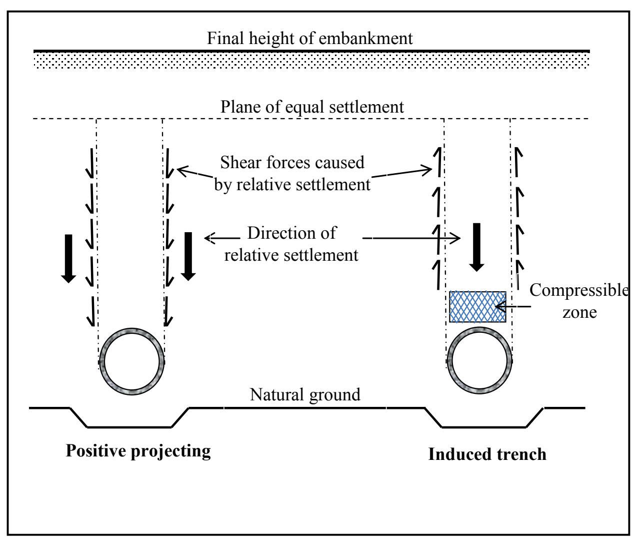

Figure 1 Positive Projecting versus Induced Trenching

The stresses measured at the crown showed a drop of 75 % in overburden pressure permitting the use of a thin membrane of steel as the roof of the culvert.

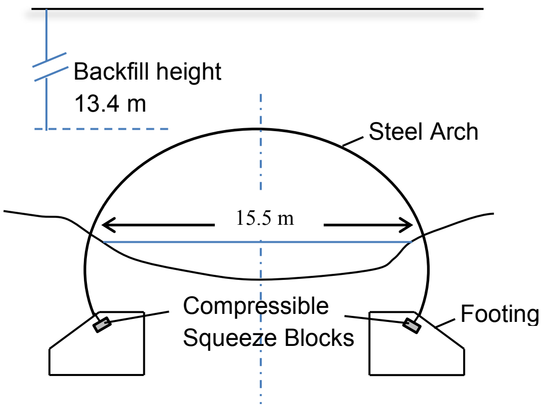

Figure 2 Culvert at Vieux Comptoir (Lefebvre et al., 1975)

Vaslestad et al., (1993) investigated the effectiveness of the induced trenching achieved using EPS geofoam layer placed above rigid culverts (1.6m diameter and 15m high). Four full scale experiments were conducted on culverts constructed between 1988 and 1992 in Norway. The reduction in vertical stresses recorded at the crown was in the range of 75% to 50% of the overburden Pressure.

McAffee and Valsangkar (2008) reported centrifuge and full scale experimental investigations of induced trenching for the culvert pipe shown in Figure 3. The pipe was 0.9m in diameter under 2m backfill installed with compressible zone made using sawdust material. A reduction of 75% in vertical pressure was recorded. It was also concluded that lateral pressure can increase in imperfect trench construction and may, in certain cases, exceed the vertical stresses.

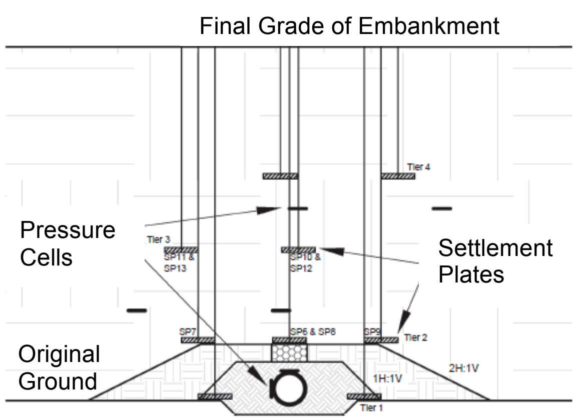

Figure 3 Induced Trench Test (McAffee and Valsankar 2008)

The above studies revealed the advantages of the induced trench installation method. In these studies, earth pressure was measured at selected locations around the pipe. However, the complete 3D distribution of contact pressure acting on the pipe is still lacking in the literature.

The objective of this study is to measure the contact pressure on a rigid pipe wall resulting from the installation of EPS geofoam layer above the pipe crown under static and repeated loading conditions.

A small scale setup has been designed and built to allow for an instrumented rigid pipe to be buried in granular material contained within a rigid box and subjected to static and cyclic loading.

Pipe deformation and earth pressure distribution along the pipe circumference are then measured for two cases: (1) benchmark tests with no geofoam; (2) tests with induced trench installation with geofoam block placed above the pipe. Details of the test setup and measured pressures are given below.

2 EXPERIMENTAL SETUP

The laboratory facilities include a Universal MTS testing machine (Figure 4) that can apply compression/tension forces up to 2,650 kN (0.6 million pounds) on specimens up to 3 meters (10 ft) high.

The machine is fixed to a strong floor located in the Structural Engineering Laboratory at McGill University. The setup consists of a strong box that houses the instrumented pipe and the granular soil used as backfill material. Details of these components are given below.

Figure 4 Experimental Setup

2.1 Strong Box

The strong box used in the experiments is illustrated in Figure 4. The box dimensions (1.4 m x 1.0 m x 0.45 m) are selected such that they represent two-dimensional loading condition. The steel surfaces were painted with epoxy coating to minimize friction with the backfill material.

2.2 Tactile Sensors

The sensors used to measure the changes in contact pressure around the pipe are custom made PPS TactArray sensors with pressure measurement range of 70 to 345 kPa (10 to 50 psi). Two sensing pads each has more than 200 square shaped sensors are used to measure contact pressure throughout this study.

In addition to the manufacturer calibration, additional laboratory testing has been conducted on the sensing pads placed over both flat and curved surfaces. A setup has been designed by creating two different wooden boxes, the first had four-sides and open from both the top and bottom and the second has two sides that are shaped to fit over the instrumented pipe. The boxes are then filled with granular material of known weight (2000 grams) and the pressure distribution as recorded by the sensors as well as the total weight are measured using the data acquisition system as shown in Figure 5. The results showed pressure readings in both cases that are consistent with the load applied.

Figure 5 Calibration of the Tactile Sensors

2.3 Backfill Soil

Crushed sandy gravel with unit weight of 16.28 kN/m^3 and friction angle of 47^o is used as backfill material in this study. A grain size distribution of the backfill soil is shown in Figure 6. The soil was placed in layers of 3 inches thick and tamped until the location of the pipe invert is reached. The invert of the instrumented pipe is then placed over a thin sand layer to protect the sensors from gravel particle intrusion and at the same time improve the contact between the soils and the pipe.

2.4 Instrumented Pipe

A rigid PVC pipe, 15 cm in diameter, was instrumented by wrapping two pads of TactArray sensors around the outer perimeter of the pipe. The sensors were connected to a data acquisition system through flexible wires located outside the tank. The sensors were protected from damage by wrapping it in two thin cover layers as illustrated in Figure 7. The first layer was made of thin rubber whereas the outer layer was made of a PVC sheet to provide contact surface similar to that of the pipe.

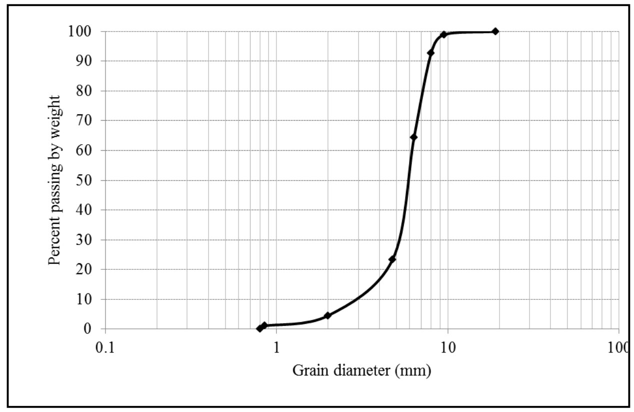

Figure 6 Particle Size Distribution of the Backfill Material

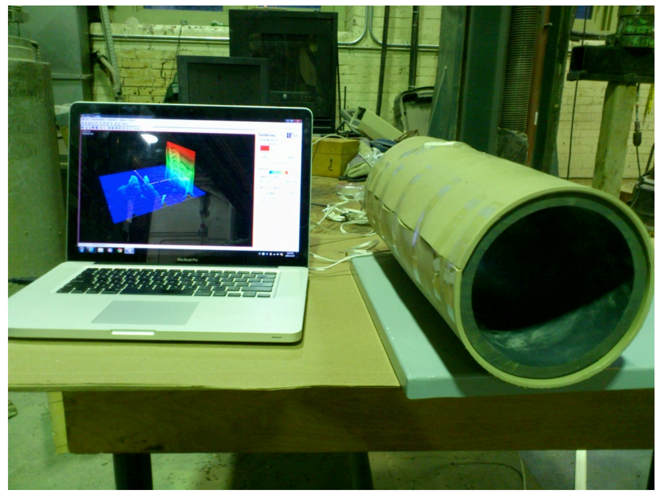

Figure 7 Instrumented Pipe with Protective Layers

2.5 EPS Geofoam

A layer of Geospec EPS geofoam (30 cm in length x 15 cm in width x 5 cm in thickness) was kindly supplied by Plasti-Fab to be used as a compressible material above the pipe throughout this study. The material properties as provided by the manufacturer are summarized in Table 1.

Table 1 Properties of GeoSpec EPS geofoam (Plasti-Fab Ltd)

Material Property	Test Method	Units	GeoSpec Type Designations
Product Density	ASTM C303	kg/m^3 (pcf)	21.6 (1.35)
Compressive Resistance Minimum @ 1% Deformation	D1621	kPa (psi)	50 (7.3)
Compressive Resistance Minimum @ 5% Deformation	D1621	kPa (psi)	115 (16.7)
Compressive Resistance Minimum @ 10% Deformation	D1621	kPa (psi)	135 (19.6)

Flexural Strength Minimum	ASTM C203	kPa (psi)	240 (35)

3 METHODOLOGY

A soil placement procedure has been developed to ensure consistent initial conditions. The pipe is installed over a compacted bedding material and the backfill is placed and tamped in layers over and around the pipe. A total of four experiments were conducted, two benchmark tests with only the instrumented pipe inside the backfill and the other two include EPS Geofoam layers installed at a distance of half inch above the pipe crown (see Figure 8). For all tests, the placement of the backfill continued up to a height of two times the pipe diameter above the crown. Earth pressure distributions were measured and compared in both cases using the tactile sensors. Surface load is then applied using a rectangular steel plate (45 cm long x 10 cm wide) attached to the actuator of the MTS machine. After the completion of each test, the tank was emptied using a vacuum machine connected to a collection barrel. The pipe was then retrieved and the setup was prepared for the next test. The load was gradually applied under displacement control through the rectangular plate with a constant displacement rate of 1.3 mm/min to simulate static loading conditions as recommended by Das, 1994.

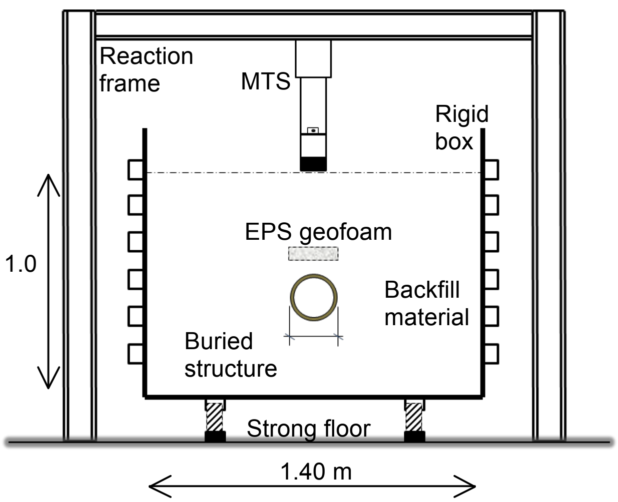

Figure 8 Schematic of the Test Setup

Figure 9 shows a geofoam block recovered after the test is completed showing the compression of the block developed during the induced trench installation.

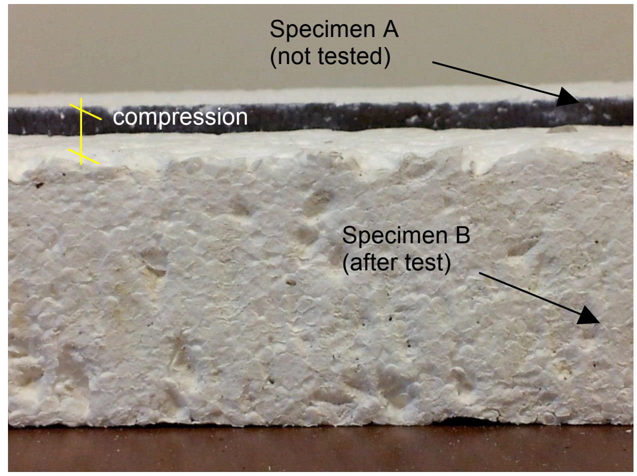

Figure 9 Deformation of a geofoam block due to induced trench

The test procedure is illustrated schematically in Figure 10. Position A shows the tank after placing the various elements described in section 3, The tank is then placed under the MTS machine as shown in position B. The MTS hydraulic jack is lowered until it comes in contact with the backfill. The loading and unloading process started and earth pressure is recorded using the data acquision system.

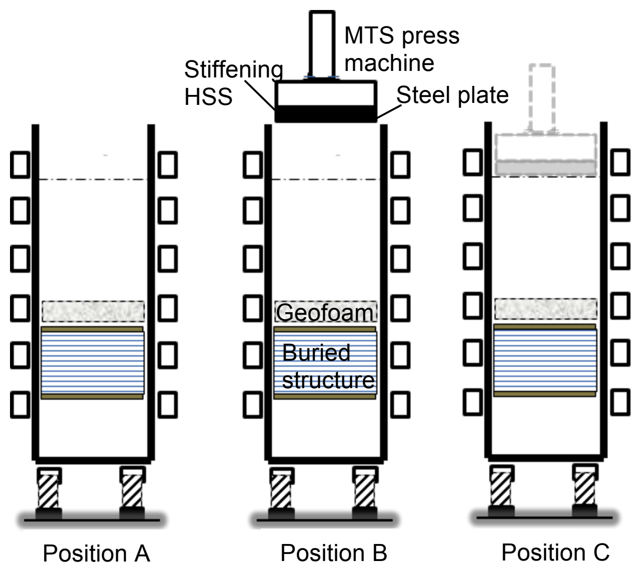

Figure 10 Testing Procedure

4 MEASURED EARTH PRESSURE DISTRIBUTIONS

In this section, the recorded contact pressure readings are compared for the benchmark case (no geofoam) and for the case where an EPS Geofoam layer is installed above the pipe.

4.1 Initial Radial Pressure on the Pipe

Snapshots of the three-dimensional earth pressure distributions for the two investigated cases (with and without geofoam) are shown in figures 11 and 12. It is worth noting that the recorded pressures were taken using two adjacent sensing pads meeting near the springline of the pipe. In the first case, Figure 11, the measured pressures at the crown, springline and invert were found to be 12, 8, and 40 kPa respectively.

These measured pressures are consistent with the negative arching that develops due to the installation of a rigid pipe using the embankment construction method over compacted bedding material. The results are also consistent with Hoeg's theoretical solution that predicts a radial pressure of 8.5 kPa at the crown. Figure 12 shows the distribution of the contact pressure for the case of geofoam block installed above the pipe.

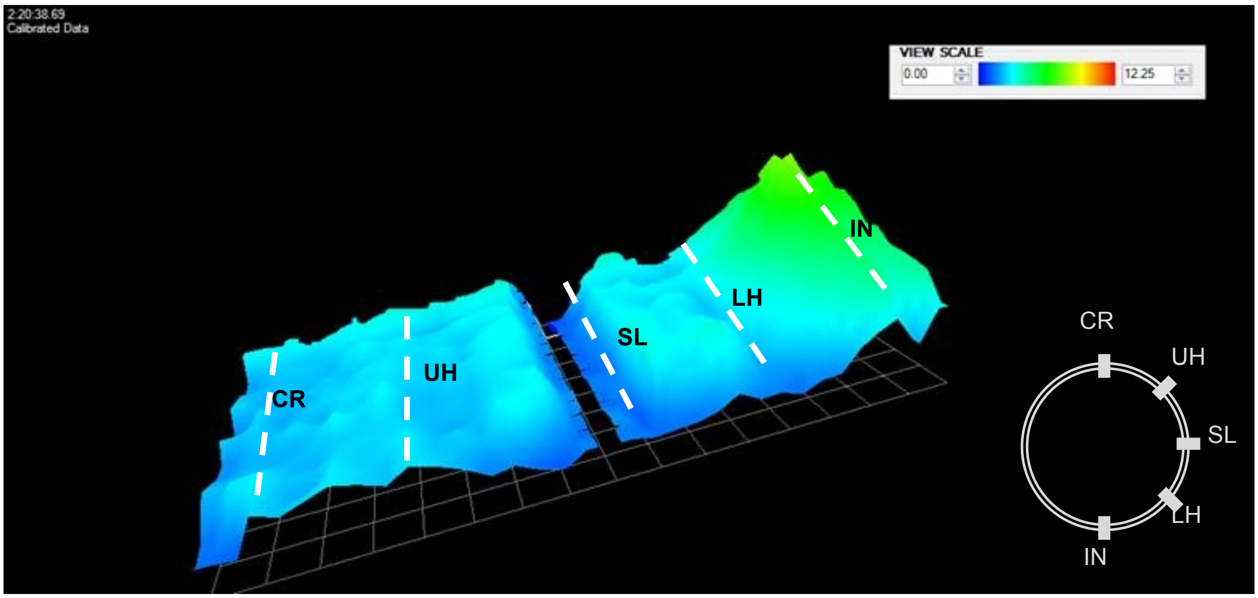

Figure 11 Initial Earth Pressure Distribution (Without Geofoam)

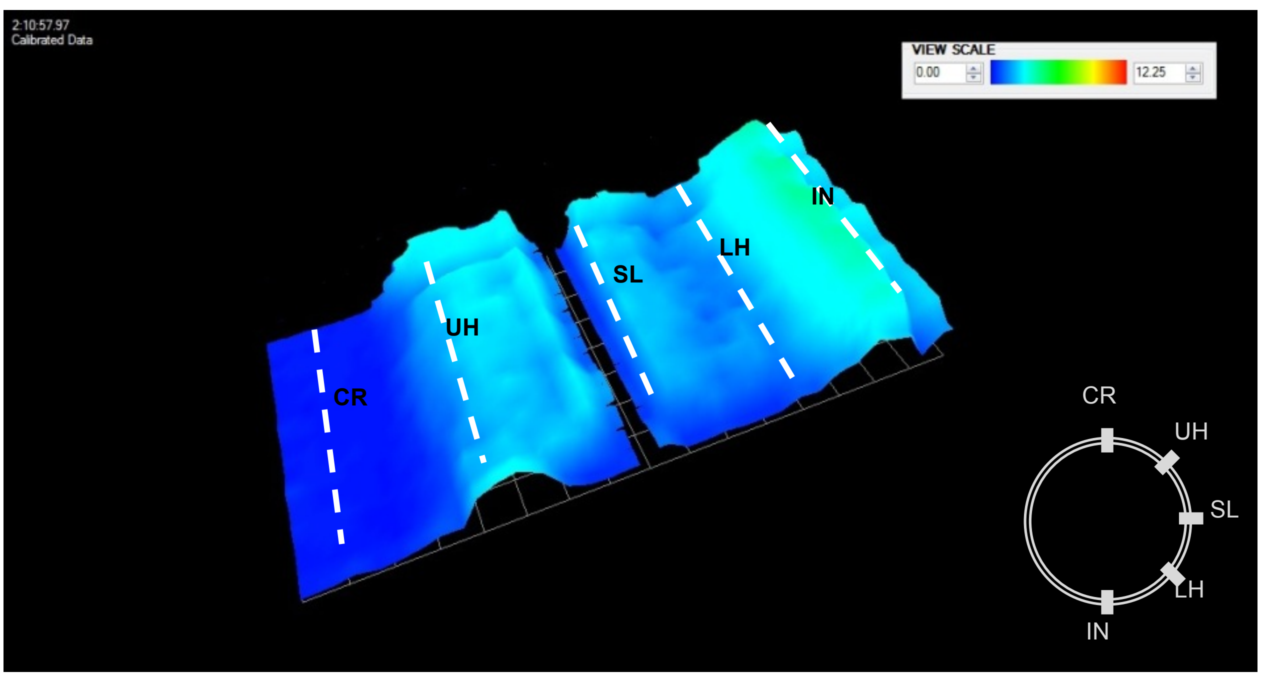

Figure 12 Snapshot of the Earth Pressures around the Pipe after Geofoam Installation

The presence of the geofoam layer was found to cause re-distribution of the earth pressures acting on the pipe with significant reduction in pressure at the crown and the lower half of the pipe circumference.
The pressure distributions at a transverse section near the middle of the pipe are shown in Figure 13. The pressure at the invert was found to be sensitive to the compaction of the bedding layer. The presented cases are for a relatively dense bedding layer.
Results show that the measured initial earth pressure varied across the pipe depending on the investigated location. A maximum pressure value of 40 kPa was measured at the crown. After the installation of the geofoam, the initial pressure at both the crown and invert locations decreased by about 10 kPa. This presents a reduction of more than 90% at the crown and about 25% at the invert.
It has been noted that the difference in pressure at the crown and invert (about 28 kPa) is equivalent to the contact pressure measured due to the self-weight of the pipe (in air). This observation is true for both initial and maximum loading conditions and confirms that, despite the sensitivity of the pressure distribution to the pipe placement procedure, the sensors are able to read the net pressure induced by the backfill material with reasonable accuracy.

4.2 Changes in Radial Pressures due to Cyclic Loading

The changes in radial pressure acting on the pipe during unloading-reloading cycles are illustrated in Figures 14 through 15 for different locations along the pipe circumference.
<u>*At the crown:*</u> Before the geofoam is introduced, the initial radial pressure at the crown was found to increase from 12 kPa to 85 kPa when the surface pressure increased from 0 to about 200 kPa as illustrated in Figure 14. After the first loading cycle is completed and the surface load is removed, the soil compression has led to an increase in radial pressure on the pipe from 12 kPa to 25 kPa. On reloading, the pressure increased from 25 kPa to 85 kPa at a slightly smaller rate.
After the geofoam is introduced, the initial radial pressure was significantly small (about 2 kPa). During the first loading cycle is applied, the pipe did not experience any increase in pressure from the initial value. Unloading and reloading did not create additional stresses in the pipe and, the recorded radial pressure did not change from 2 kPa
<u>*At 135 degrees (lower haunch):*</u> The initial pressure for the case of no geofoam started from about 16 kPa and increased to 50 kPa as the surface pressure increased to 200 kPa. Upon unloading, the initial pressure returned to

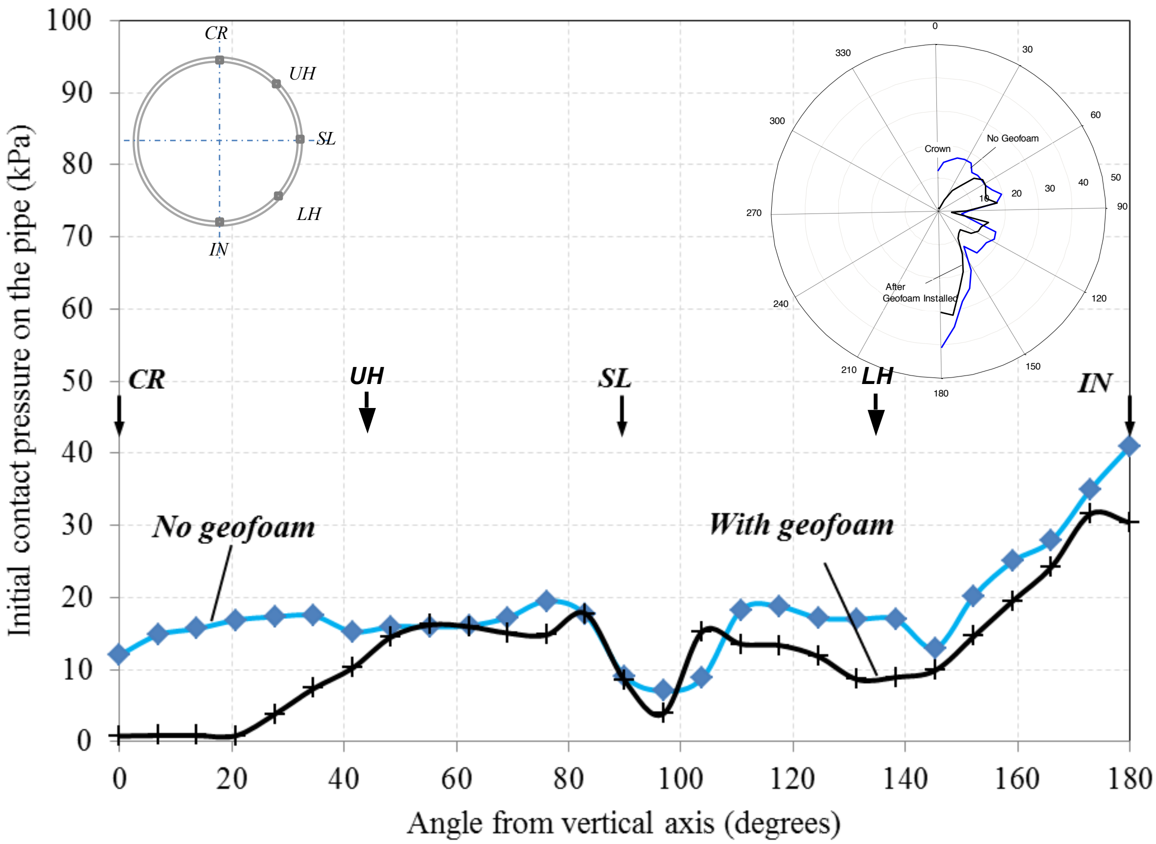

Figure 13 Initial Earth Pressure Distribution on the Pipe

26 kPa with a residual value of about 10 kPa as shown in Figure 15. The presence of the geofoam reduced the initial pressure to 12 kPa with a maximum pressure of 37 kPa when the surface load reached 200 kPa. It can be seen that at this location the presence of the geofoam was found to reduce the radial pressure by about 40% following the completion of the repeated load cycles.

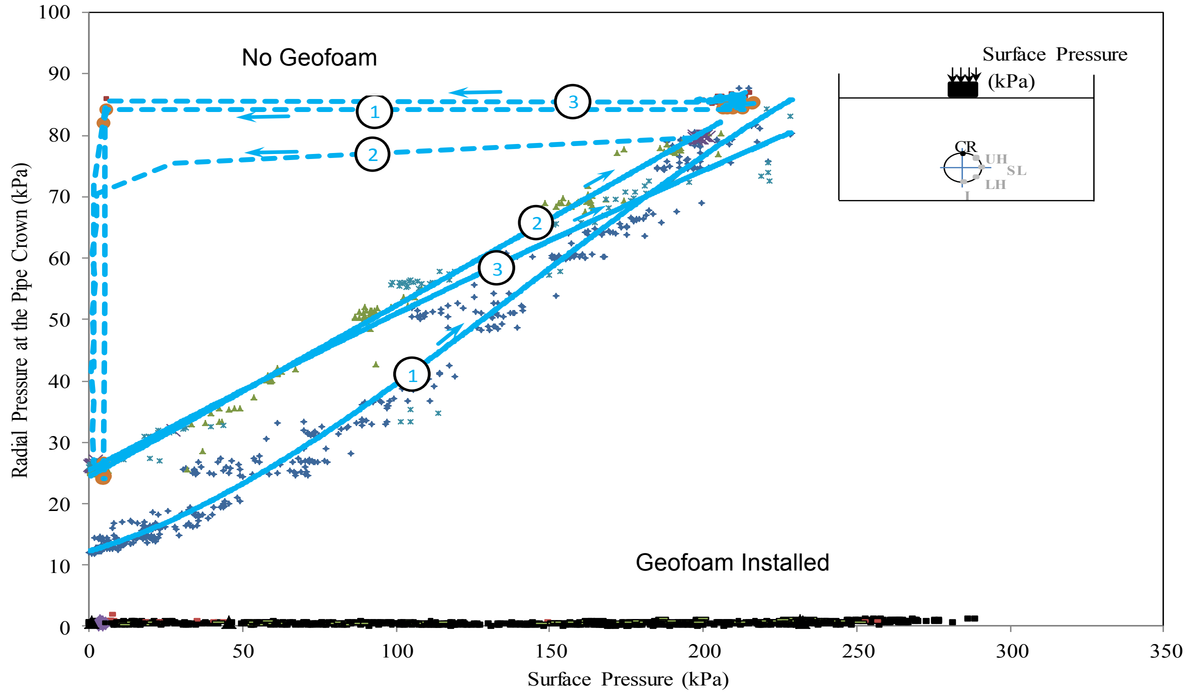

Figure 14 Earth Pressures in Cyclic Loading (Crown)

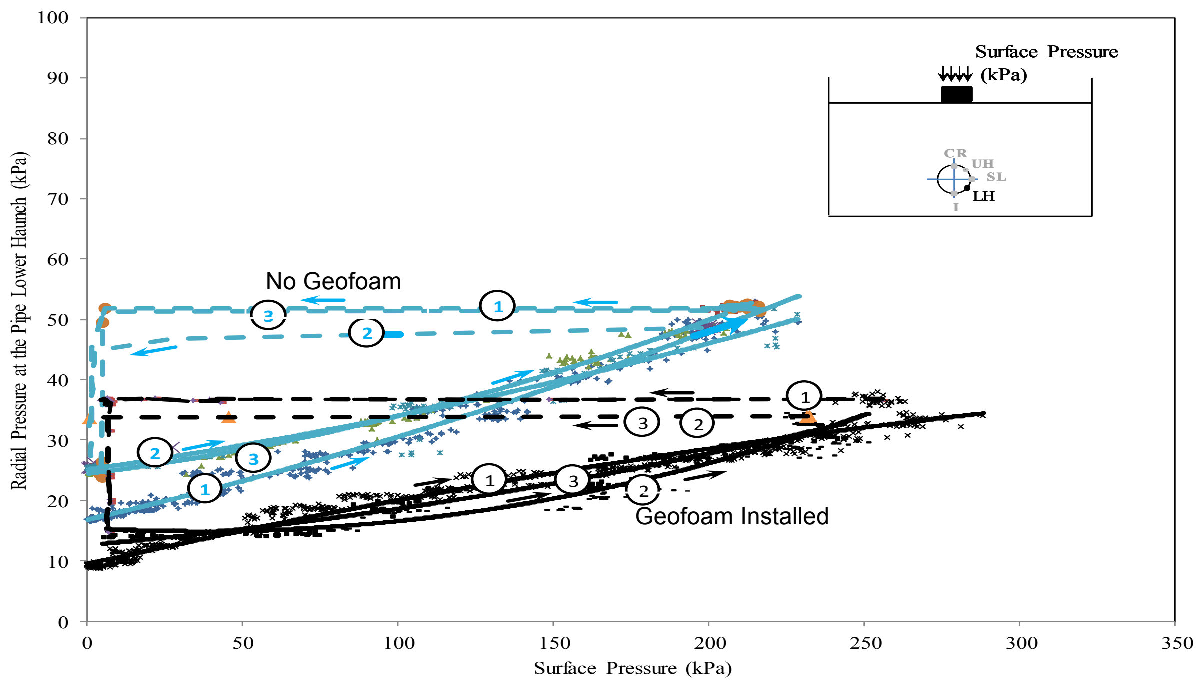

Figure 15 Earth Pressures in Cyclic Loading (Lower Haunch)

5 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

This study examined the effect of installing Geospec EPS geofoam manufactured by Plasti-Fab on the earth pressure distribution on buried pipes installed using the embankment construction technique. A large scale test setup was designed to allow for a granular backfill material to be contained in a rigid box and for a surface pressure to be applied using an MTS press machine. A rigid PVC pipe was instrumented using conformable TactArray pressure sensors wrapped around the outer perimeter and installed within the backfill material. To examine the effect of introducing a geofoam layer above the pipe on the radial pressure induced by surface loading, a relatively shallow burial depth of two times the pipe diameter above the crown was chosen in this study. This depth was found to be appropriate to ensure that sufficient load is transferred to the pipe during the loading and unloading process.

Two sets of experiments were conducted- the first included two benchmark tests with no compressible layer and the second included two tests with a geofoam layer installed above the pipe. For the investigated geofoam density, geometry and the type of backfill material, the presence of the geofoam caused significant reduction in radial earth pressure at the crown and invert. A summary of the measured pressure changes are given the following Table.

Table 2 Measured pressure changes

Location	% Change in radial pressure	% Change in residual pressure after unloading
CR (0^o)	-90%	-100%
SL (90^o)	-35%	No residual stresses in both cases
IN (180^o)	-25%	+10%

Further testing is recommended to study the effect of the geofoam density and thickness on the changes in radial earth pressure on buried pipes.

6 ACKNOWLEDGEMENTS

The experimental work reported in this study is conducted by a graduate student: Mahmoud Ahmed assisted by one graduate student (Gholamreza Saghaee) and two summer students (Derek Lu and Hubert Peloquin), their contribution is greatly appreciated. This project is supported by NSERC Engage Grant funding (Grant No.412217-12), in addition to the in-kind contribution from Plasti-Fab Ltd. The assistance of Mr. John Bartczak in setting up the experiment and calibrating the sensors is really appreciated.

7 REFERENCES

Das B.M., Shin E.C., Omar M.T. 1994. The bearing capacity of surface strip foundation on geogrid reinforced sand and clay – a comparative study *Journal of Geotechnical and Geological Engineering*, 12 (1): 1–14

Hoeg, K. 1968. Stresses against underground cylinders. Journal of Soil Mechanics and Foundation Engineering, ASCE, 94 (4): 833-858.

Larsen, N.G. 1962. A practical method for constructing rigid conduits under high fills. *Highway Research Board Proceedings*, 41: 273-280.

Lefebvre, G., Laliberte, M., Lefebvre, L.M., Lafleur, J. and Fisher, C.L. 1976. Measurement of soil arching above a large diameter flexible culvert, *Canadian Geotechnical Journal*, 13 (1): 58-71.

McAffee, R.P., and Valsangkar, A.J. 2008. Field performance, centrifuge testing, and numerical modelling of an induced trench installation. *Canadian Geotechnical Journal*, 45(1): 85–101.

Plasti-Fab Ltd. 2012, Product Information Bulletin.

Vaslestad, J., Johansen, T.H., and Holm, W. 1993. Load reduction on rigid culverts beneath high fills: Long-term behaviour. *Tranportation Research Record 1415, Norwegian Road Research Laboratory, Public Road Research Administration*: 58-68.