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INVESTIGATING THE BEHAVIOR OF A BURIED FLEXIBLE PIPE COVERED WITH EPS GEOFOAM

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ABSTRACT

This paper presents a part of the findings obtained from true-scale laboratory model tests which were performed for the purpose of investigating the effects of "compressible zone" application on buried HDPE pipe behavior (i.e. soil stresses, wall strains and deflections). The test pipe was fully covered with compressible fill material and EPS Geofoam with 10 kg/m³ nominal density was used as the compressible fill material. A reference test with pipe and soil only was also performed for comparison. It has been determined that when the flexible pipe is covered with EPS Geofoam, pipe deflections, pipe wall strains and soil stresses on pipe wall are reduced significantly.

1. INTRODUCTION

Highway or airport constructions may require construction of high embankments where the fill height above the top of buried rigid and flexible utilities may be greater than 10 m. The high embankment fills may impose significant earth loads on the underground structures. When high embankment fills are required over rigid culverts, the installation methods typically used are the positive projection installation or the induced trench installation. The induced trench installation (ITI) method introduces a zone of compressible material such as EPS Geofoam above the culvert. The concept behind this method is to reduce the vertical earth pressure on the utility by the inclusion of a lower density fill material (compressible layer), thus reducing the load over the utility, but also inducing positive arching. The compressible material above the utility line causes differential settling of the column of soil directly above the utility relative to the adjacent soil. The earth load from the column of soil directly above the culvert is partially supported by the shear forces developed on the soil interface with adjacent soil columns, thereby resulting in some of the load being redistributed to the adjacent fill.

The use of HDPE pipes has become more widespread in recent years due to its advantages over concrete and steel pipes, and numerical analyzes, laboratory and field tests have been carried out to study pipe-soil interaction under load and studies are still in progress. Since the HDPE pipe will be deflect under vertical loads and a slight amount of arching will develop and as a results the vertical stress acting on it decrease, but the lateral stress increases. Efforts are continuing to make more economical designs by reducing the stresses that are transferred to the pipe by increasing the effect of arching on the flexible pipes. The reduced earth pressures also allow savings in the design for the pipe/culvert walls. Furthermore, the use of EPS Geofoam offer significant savings in time, cost and quality compared to the use of natural fill materials.

The pipe-soil system response includes soil stresses around and above the buried pipes, pipe deflections, and pipe wall strains. The type of soil used to surround the pipes was found to have a considerable influence on pipe

behavior. Soil pressure results from the combination of soil weight and surface loads. As backfill is placed around and over a HDPE pipe, the soil pressure increases and the pipe deflects vertically and expands laterally into the surrounding soil. The lateral expansion mobilizes passive resistance in the soil which, in combination with the pipe's inherent stiffness, resists further lateral expansion and consequently further vertical deflection. The magnitude of the deflection and the stress depends not only on the pipe's properties but also on the properties of the surrounding soil. The magnitude of deflection and stress must be kept safely within PE pipe's performance limits. Excessive deflection may cause loss of stability, excessive compressive stress may cause wall crushing or ring buckling. The performance of such buried pipes hinges on uniformly well-compacted granular soil on both sides of the pipe. Soft soil or compacted soil on only one side will allow for deformation, leading to possible collapse or buckling of the pipe. It has been determined that EPS Geofoam can be used to surround the pipe all around in applications where uniformsoil conditions and controlled backfill is not possible.

Since its use as an EPS engineering material, it has begun to be used as a compressible material in the ground during geotechnical applications as of the late 1980s. The EPS Geofoam is produced as a block or panel, in practice it is positioned between the structure and the soil (usually between the direction of the load and the structure). Stress-strain characteristics are standardized for different densities(ASTM D6817/D6817M, 2015) and it is a light material that can be produced in the desired geometric form.Vaslestad et al. (2011) observed soil stresses on four rigid culverts buried with Imperfect Trench Installation (ITI) using EPS Geofoam in Norway between 1988-1992.The pressure on buried structures can be reduced with the appropriate selection of backfill material with higher stiffness like granular material. At the end of 20 years average measured earth pressure above the crown of the pipe ranged from 23% to 25 % of the overburden pressure for installations with granular backfill material and about 45 % for the one with cohesive backfill material. In the later years, this method of using Geofoam to reduce earth pressure have also been used on concrete culverts below high fills in China, Yang et al. (2005), Zhang et al. (2006) and McAfee and Valsangkar (2008).The compressible soft zone geometry is traditionally defined by three parameters: width, height, and the distance from the top of the pipe to the bottom of the soft zone. For circular pipes, Vaslestad et al. (1993) studied a condition where the pipe is inserted into a zone of soft material. Yoo and Kang (2007) concluded, based on a large number of parametric studies that, compared to other configurations, surrounding the pipe with a soft zone was found to be the most effective in reducing earth pressures (Meguid, et al. 2017). Limited efforts have been made to date to investigate the effect of EPS configuration on the loads transferred to the walls of a buried pipe deflection, particularly, for flexible pipe wall and deflection under high embankments.

In this study, the effects of imperfect trench installation on behavior of a small-diameter lined-corrugated wall HDPE pipe were investigated in a series of true scale tests conducted in a laboratory setup. Inspired by the soft zone geometry proposed by Kang et al. (2008), two "saddle-shaped" EPS Geofoam, geometries of which were roughly designed, were also installed both above the crown and below the invert of the pipe. Thus, the pipe was covered with EPS Geofoam.

2. TESTING FACILITY AND MATERIALS

Laboratory model tests were conducted using the laboratory test facility, in which burial medium that is 1.5 m wide x 1.5 m long x 1.5 m high is restrained by four stiff walls (three of each are 10 mm-thick steel and one is 30 mm-thick plexiglass) and a steel base. The walls are surrounded by steel box profiles at the top, mid-height and bottom levels, and are supported by vertical steel supports (four on each wall) to minimize undesirable outward movement due to lateral earth pressures. Another component of the facility is a loading frame. Columns of the frame are welded to the walls (i.e. connected to the base through the walls) so the base itself is to work as a reaction plate. Vertical pressures are applied to ground surface through a rigid plate (made of steel) using two hydraulic pistonts with 50 ton-loading capacity. A cross-section through the test facility is shown in Figure (1).

Test tank walls were reinforced with vertical steel supports and steel box profiles beam supports for the purpose of minimizing outward movement under the largest surcharge load. Displacement sensors measured an outward movement just about 0.01 mm under 200 kPa surcharge stress and it therefore the test tank was assumed to be sufficiently rigid (Kilic, et al. 2014).

Test pipe, manufactured by Dizayn Group, was a lined-corrugated wall HDPE pipe with a nominal internal diameter of 300 mm. Ring stiffness of the pipe was determined as 8.8 kN/m³ in accordance with TS EN ISO 9969. Sectional properties of lined-corrugated wall is given in Figure 3. Three pipe pieces, cut to a length of 490 mm, were supplied. This was required to facilitate placing instrumentation inside the pipe. After placing the instrumentation, the pieces were jointed by butt-welding.

The soil used in the tests was dry sand with a coefficient of uniformity (C_u) of 2.57, a coefficient of curvature (C_c) of 0.92 and an effective size of particle (D_{10}) of 0.35 mm. The specific gravity was 2.65. The soil could be classified as poorly graded sand (SP) according to the Unified Soil Classification System. The maximum and minimum dry weights of the sand were found to be 17.3 kN/m³ and 14.4 kN/m³, respectively.

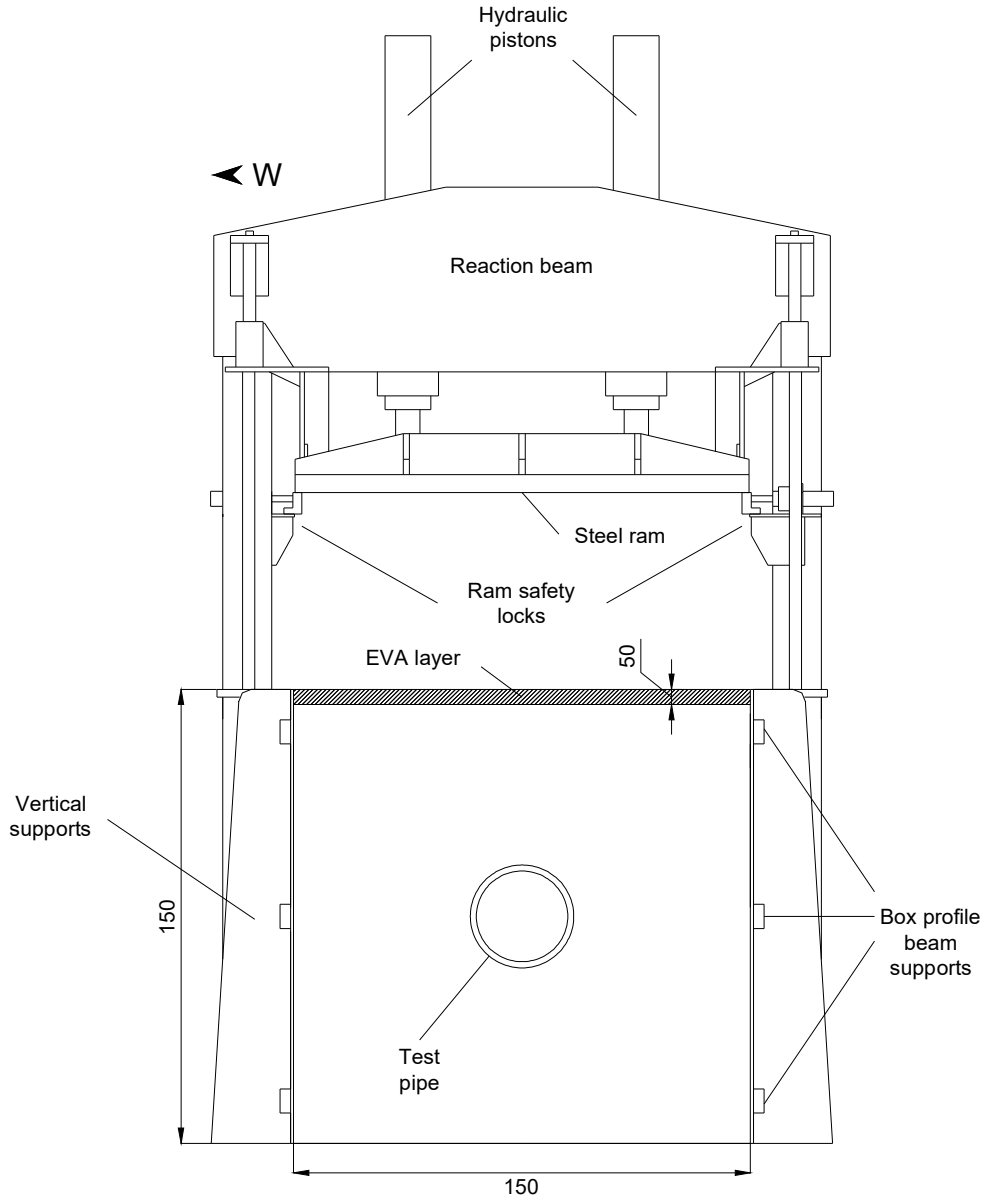


Figure1. Schematic of the testing facility (West to East direction, all units are in cm)

Instrumentation was placed only at the mid-length cross-section. Potentiometric displacement sensors (Burster 8709-5100) were used to measure vertical and horizontal pipe deflections (Figure 2). Diaphragm-type earth pressure cells were used to measure vertical stress on pipe crown and pipe invert (TML KDG-500PA); and horizontal stress on pipe springline (TML KDG-200PA). Earth pressure cells were placed in contact with pipe wall (Figure 2). Biaxial strain gauges with (Omega SGK-B3A-K350U-PC11-E) were placedon different locaions on the wall profile to measure surface strains in both circumferential and axial directions (Figure 3). Strain gauges were placed with 30° intervals on the pipe wall. Strain gauges on valley were placed on whole circumference of the pipe, while other strain gauges were placed on half circumference of the pipe.

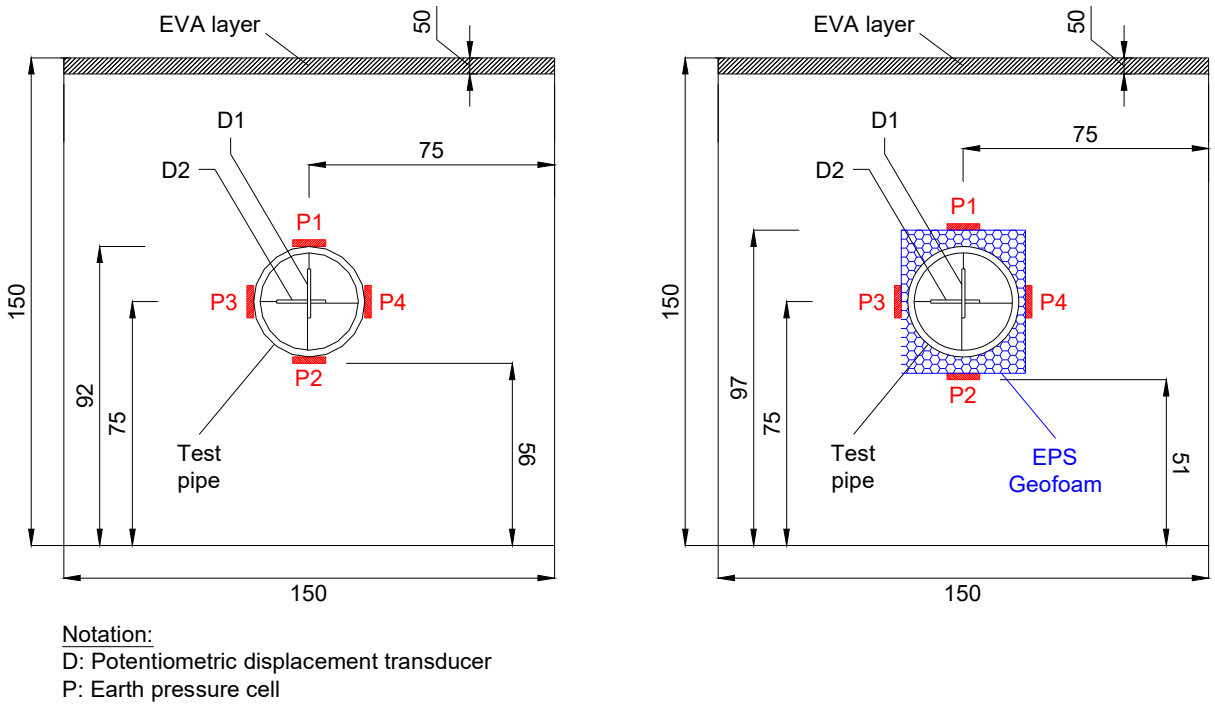


Figure 2. Location of pipe and instrumentation in test tank; Reference Test (at the Left) Test #1 (at the Right)

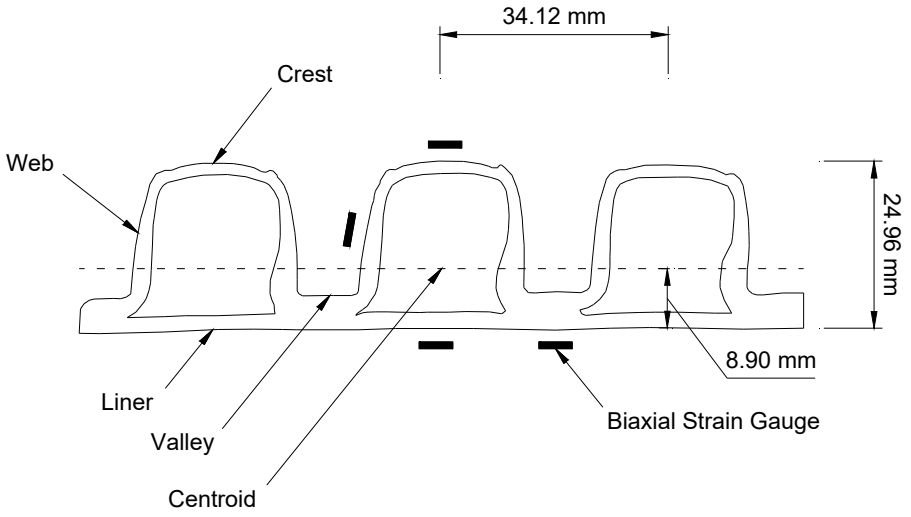


Figure 3. Loactions of biaxial strain gauges on pipe wall profile

Friction between the walls and the soil was minimized by placing two 0.08 mm-thick polyethylene sheets, lubricated with Dow Corning Molykote 44 High-Temperature Bearing Grease (Medium), along the walls. Placing a protection layer on polyethylene sheets for avoiding any possible damage due to particle impingement was also considered to be necessary. Conservatively, placing a non-wowen geotextile (with a mass per unit area of 150 g/m) layer on which 2 mm-thick HDPE geomembrane plates were attached was adopted for this purpose. This arrangement reduces the boundary friction to less than 5% (Tognon et al. 1999), and leads to less than a 5% decrease in vertical stresses reaching the pipe (Brachman et al. 2001, 2008).

Test soil was loosely placed (by dropping from a height as low as possible) in layers. Approximately 500 kg of sand used for each layer,which corresponds to about 140-150 mm in thickness. In order to measure the density of the soil, two standard Proctor molds (with a diameter of 10 cm and a depth of 11.7 cm) were placed randomly on the surface of the layer just before getting started to place the soil.After placing the soil, the molds were carefully removed from the inside of the layer and weighed. Layer surface was afterwards levelled and no compaction was efforted. GeoGauge, developed by Humboldt, was used to measure placement uniformity of the soil. Optimum number of GeoGauge readings were taken from surface of each layer. After placing the fourth soil layer, the pipe

was installed. When installing, one end of the pipe was rested against the north wall of the cell while a ring, cut out of an XPS board, was placed in the gap between the other end of the pipe and the south wall of the cell. A foam ring avoids sand to fall into the gap, however the pipe ends, which possibly might be restrained, may lead to non-zero axial stresses along the pipe. It should also be noted that one personnel had to get into the tank and walk on the soil to facilitate installing the pipe. During this operation, care was taken not to walk on the soil section where the pipe was laid on.

In the previous work, it's stated that using a pressurized air bladder is a better way of providing uniform vertical stress distribution on the ground surface (Brachman et al. 2000, 2001). However, in this study vertical load was applied to the ground surface through a rigid plate. It's known that this way of loading leads to a non-uniform vertical stress distribution on the ground surface. Therefore, a 50 mm-thick compressible material layer was placed between the rigid plate and the ground surface to enable the vertical stresses to distribute more uniformly. Ethylene vinyl acetate (EVA) was found to be a proper material because of its high compressibility and linear elastic strain-stress behavior.

The vertical pressure was applied in successive 25 kPa increments, with each increment held for 30 min to permit measurements to be taken after the soil and pipe responses had stabilized. Considering the capacity of the hydraulic pistons, the experiments were conducted to a maximum vertical pressure of 200 kPa, which corresponds approximately to the vertical stress imposed by the weight of a 10 meter high well-compacted soil.

Figure 4 shows the pipe covered with EPS in the model test setup. Also there are strain gauges installed on the pipe and settlement plate placed on the sand layer beside EPS.



Figure 4. Pipe instrumentation and pipe-compressible zone configuration" (Akinay, E. 2015)

2.1 Experiment Results

In Figure 5, comparison of the measurement results obtained from the stress cells in the Reference Test and Test #1 were made.Figure 5a shows on the pipe crown,Fig. 5b is the bottom of the pipe (invert) and Fig. 5c is the comparison of the measured stresses in the pipe side walls. For a stress stage of 200 kPa, the vertical stress acting on the pipe in Test #1 is 77% of the value measured in the Reference Test (Fig.5a) and the stress on the bottom of the pipe is 44% less than the value measured in the Reference Test (Fig. 5b).The mean lateral stress on the pipe side wall in Test1 is 75% less than the value measured in the Reference Test (Fig 5c).

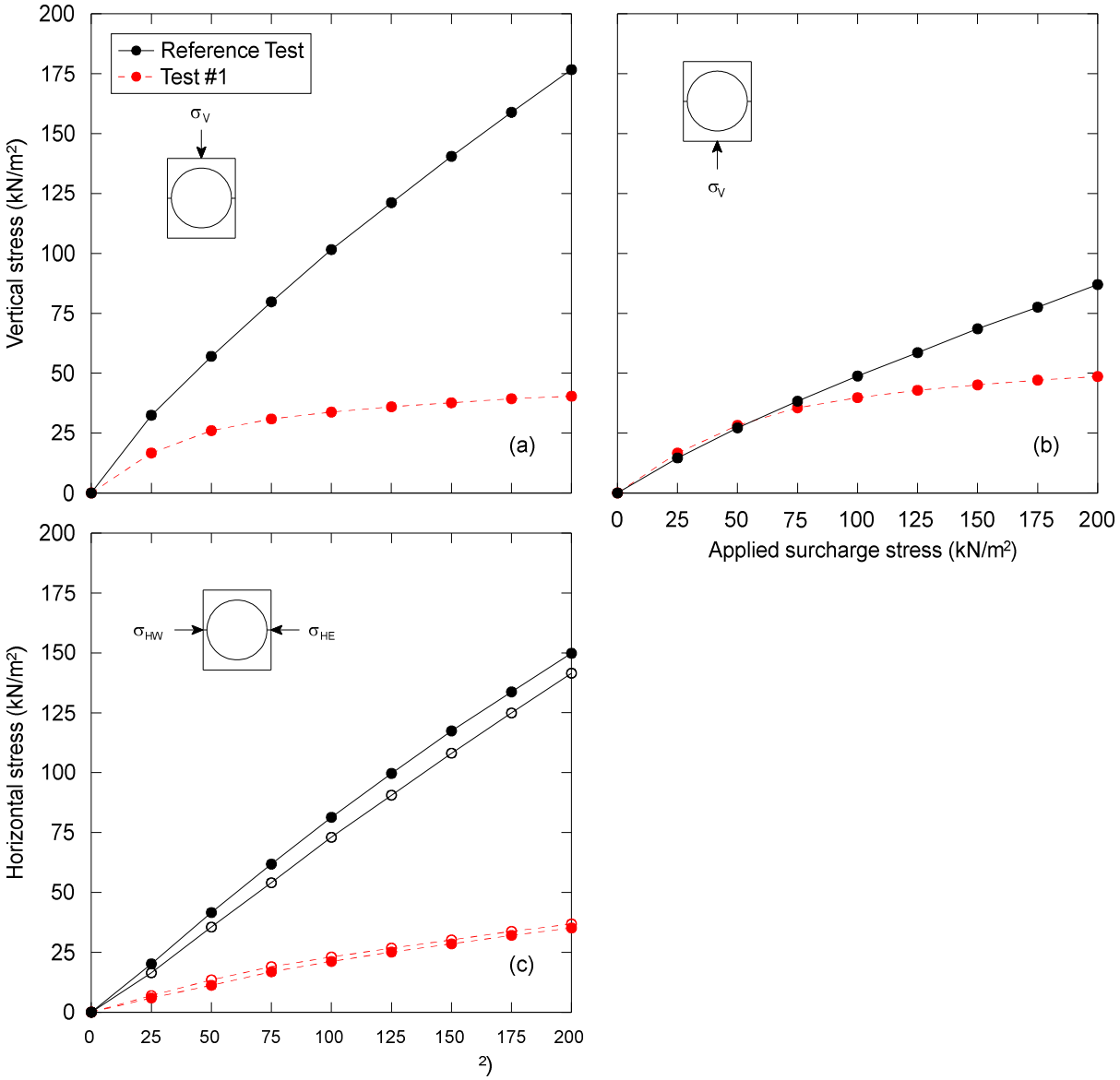


Figure 5. Comparing the stresses measured in Test #1 with the Reference Test results a)pipe crown b)pipe invert c) pipe springline

Figure 6 shows the deflection of the pipe. For a stress stage of 200 kPa, in Test #1, the vertical and horizontal deflections of the pipe are 89% and 96% less than the values measured in the Reference Test, respectively.

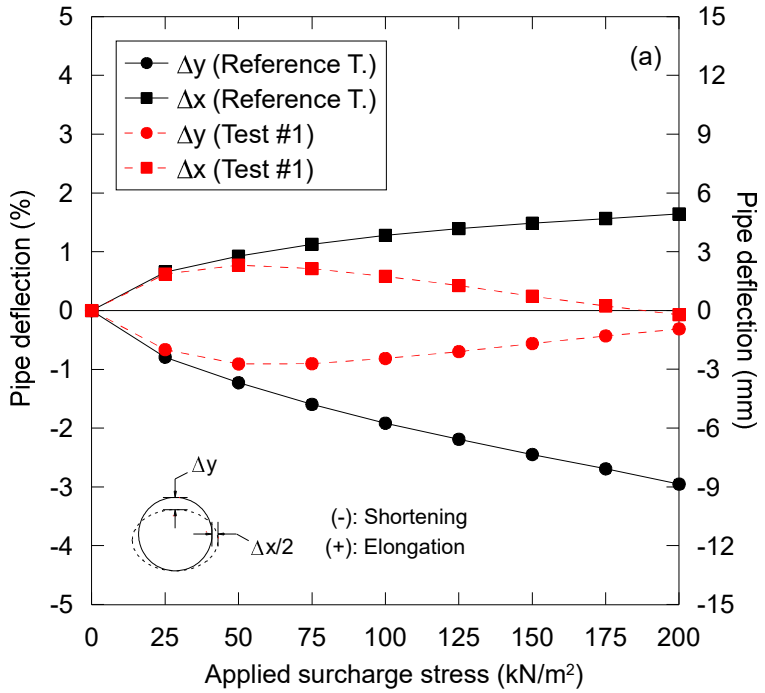


Figure 6. Variation in the diameter of the pipe vertically and horizontally(Akinay, E. 2015)

In the stress stage of 200 kPa, the strains in circumferential and longitudinal directions in the liner and crest on the corrugation of the outer surface of the pipe and web and valley on the inner surface of the pipe are shown in Fig. 7. Figures 7a and 7b compare the measurements taken in the circumferential and longitudinal directions respectively in the liner and crest on the pipe inner surface. It is seen that the measurements in the circumferential direction are very close to each other, but the measurements in the longitudinal direction are different from each other. Measurements from Test #1 show a uniform shape change around the pipe.

3. CONCLUSIONS AND RECOMMENDATIONS

In this study, the stresses, strain and pipe deflections on the high density polyethylene pipe (HDPE) which will remain under high fill have been experimentally investigated. A laboratory setup has been designed for theinvestigation of pipe behavior. The effects of imperfect trench installation on behavior of a small-diameter lined-corrugated wall HDPE pipe were investigated in a series of true scale tests conducted using this laboratory test facility. Inspired by the soft zone geometry proposed by Kang et al. (2007), two “saddle-shaped” EPS Geofoam, geometries of which were roughly designed, were also installed both above the crown and below the invert of the pipe. Thus the pipe has been covered with EPS Geofoam.

The use of EPS Geofoam by creating a soft zone around the pipe increases the positive arching of the HDPE pipe. As a result, the bigger portion of the load is transferred from the central soil prism above the crown and below the invert to those adjacent to the pipe. The reduction in vertical soil stress acting on the crown, invert and pipe side walls were found to be 77%, 44% and 75% less than the values measured in the Reference Test respectively in Test #1 where EPS10 Geofoam were used as compressible soft zone.These findings indicated that a relatively compressible inclusion induces positive soil arching mainly in the zone where it’s present, i.e. above the crown level or below the invert level.

The minimum deflections were measured at the 200 kPa stage loading in Test #1 in which the pipe was covered with EPS Geofoam. In this test, the maximum absolute value of vertical and horizontal deflections were measured as 0.40% and 0.65%, respectively. These values are 87% and 60% less, respectively, than those measured at the Reference Test in which no EPS Geofoam was used.

The results obtained for this study were obtained for a lined-corrugated wall HDPE pipe with a nominal internal diameter of 300 mm.Field tests are recommended to generalize the results.

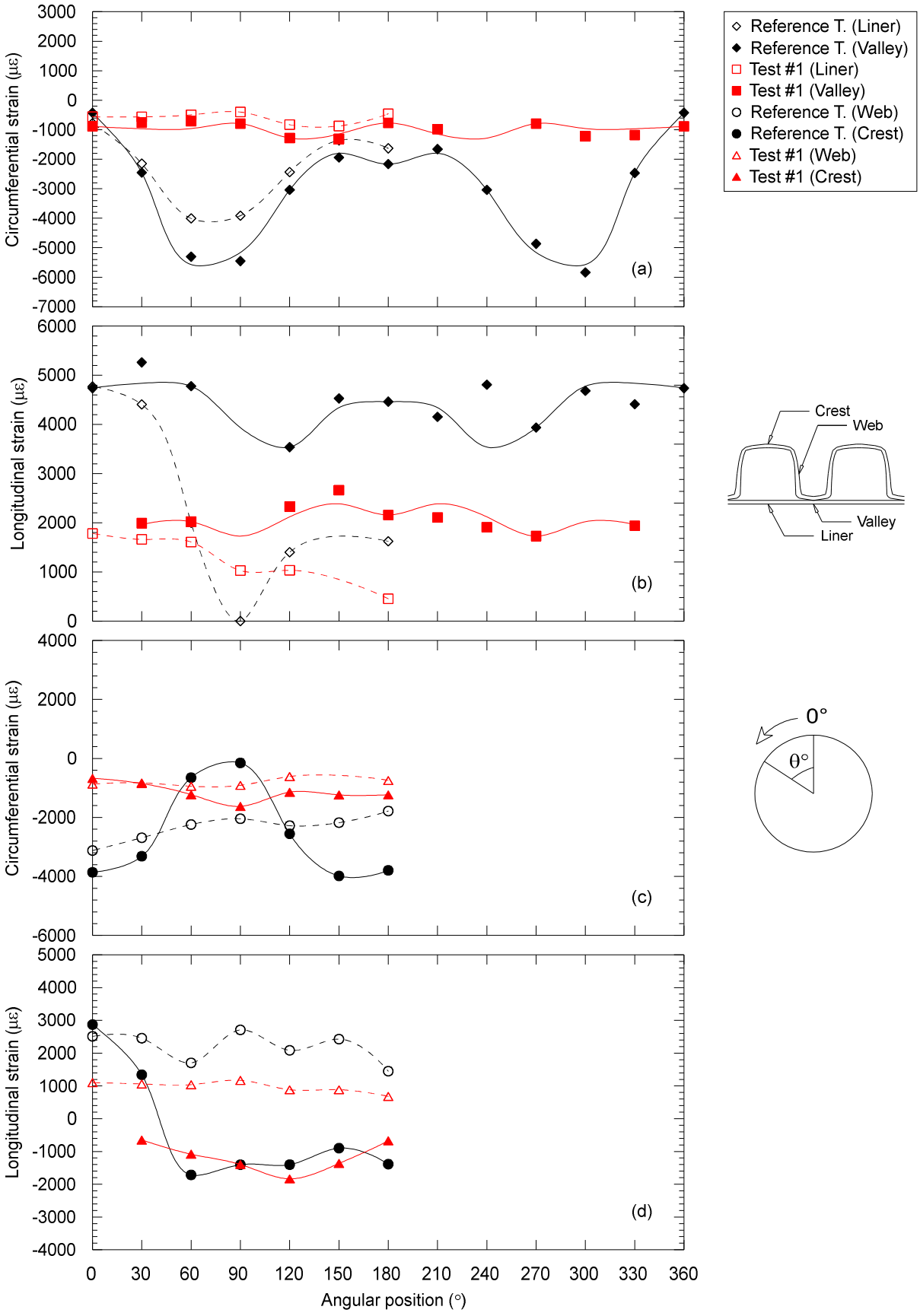


Figure 7. Comparison of strain measurements at 200 kPa in crest, liner, web and valley a)circumferential b) and b) longitudinal direction(Akinay, 2015)

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