

Protection of Buried Pipe under Repeated Loading by Geocell Reinforcement

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Abstract. With increase in cities' population and development of urbane life, passing buried pipelines near ground's surface is inevitable in urban areas, roads, subways and highways. This paper presents the results of three-dimensional full scale model tests on high-density polyethylene (HDPE) pipe with diameter of 250 mm in geocell reinforced soil, subjected to repeated loading to simulate the vehicle loads. The effect of geocell's pocket size (55*55 mm and 110*110 mm) and embedment depth of buried pipe (1.5 and 2 times pipe diameter) in improving the behaviour of buried pipes was investigated. The geocell's height of 100 mm was used in all tests. The repeated load of 800 kPa was applied on circular loading plate with diameter of 250 mm. The results show that the pipe displacement, soil surface settlement and transferred pressure on the pipe's crown has been influenced significantly upon the use of geocells. For example, the vertical diametric strain (VDS) and soil surface settlement (SSS), in a way that using a geocell with pocket size of 110*110 mm reduces by 27% and 43%, respectively, compared with the unreinforced one. Meanwhile, by increasing buried depth of pipe from 1.5D to 2D, the use of geocell of 110*110 mm delivers about 50% reduction in SSS and VDS, compared with the unreinforced soil.

1. Introduction

Even though, or perhaps because, buried pipes are popular, they may suffer from insufficient quality control, resulting in poor installation, and little or no inspection and maintenance. To evaluate the behaviour of pipes embedded in soils, there are different methods out of which some were of great significance such as field studies, experimental studies, numerical analysis, that each one is of interest in understanding one aspect of soil-pipe interaction, and also proper to predict pipe response. A large number of studies have been carried out in this respect by researchers [1-11]. Geosynthetic application is one of the engineering solutions which employed to improve the behaviour of foundation beds [12-18]. Although, some researchers have studied the pipe response in planar reinforced trench soil [19-20], but there is little literature studying the pipe behaviour in geocell reinforced trench subjected to surface loading.



Hence, in the current study the aim is to investigate experimentally the behaviour of embedded pipes in soil bed, having reinforcing layer of geocell, subjected to repetitive loading like traffic loads (loading, unloading and reloading). This type of loading can represent the impact of traffic loads (such as car and train wheels) on pipes behaviour. With applying repetitive loads on soil surface, some features like the settlement of soil surface, pipes displacements, and transferred pressure on pipe are taken into account through experimental tests.

2. Research Objectives

Use of geocell reinforcements in the trench above the pipe has the potential to limit deformation of the pipe and to prevent its probable premature cracking under various loading. This study aims to develop further an understanding of the influence of geocell reinforcement with different cell opening area and pipe embedment depth on the behaviour of buried pipes subjected to repeated loads. The specific aims are investigation the effect of following parameters on deformation of, and exerted pressure on, the buried flexible pipes:

- geocell's pocket size (55×55 mm and 110×110 mm);
- embedment depth of buried pipe (1.5 and 2 times pipe diameter);
- simulating the traffic load (repeated loading)

3. Test Materials

3.1. Soil

In order to simulate real testing conditions and having possibility of manually filling and discharging trench at the right time, the sandy soil in vicinity of wall and crown of pipe was used as shown Fig. 1. As seen, in this type of soil maximum grain size and mean grain size are 20 mm and 4.3 mm, respectively. This soil is classified as “SP” according to Unified Soil Classification System (ASTM D 2487-11) which is most common in geotechnical projects. It is noteworthy that the grain size of current soil will satisfy the limitation of maximum grain size placed on pipes according to ASTM D2321-08 which is 38 mm.

3.2. Geocell

The used geocell is a particular 3D geosynthetic formed from strips of non-woven geotextile that are thermo-welded into a cellular and honeycomb-like system.

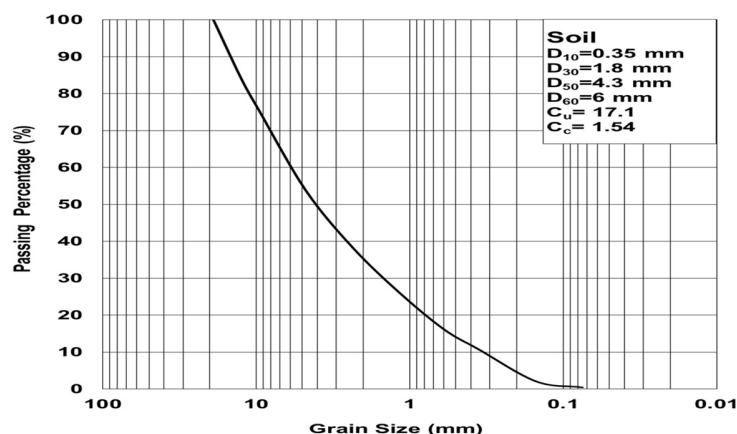


Figure 1. Grain size distribution curve

The geocell layers were used in two pocket sizes of 55×55 mm and 110×110 mm while the thickness of the geocell layers (H) was kept constant at 100 mm in all tests. The engineering properties of this geotextile to form the geocell are tabulated in Table 1.

Table 1. The Engineering Properties of the geotextile

Description	Value
Type of geotextile	Non-woven
Area weight (gr/m ²)	190
Thickness under 2 kN/m ² (mm)	0.57
Thickness under 200 kN/m ² (mm)	0.47
Tensile strength (kN/m)	13.1
strength at 5% (kN/m)	5.7
effective opening size (mm)	0.08

3.3. Pipe

With regard to technology development and expansion of using Polyethylene pipes in urban consumptions and sewerage system, the polyethylene pipes were used in the tests. So, a number of pipes have been prepared from different factories and a diverse bunch of tests have been conducted in order to verify the repeatability of pipes behaviour in similar conditions. Finally, the polyethylene pipe with pressure of 4 bar and high density of PE 100 having diameter of 250 mm and length of 1500 mm (made by Gostaresh Co.) was chosen. The properties of the pipes, as listed by the manufacture are presented in Table 2.

Table 2. Engineering properties of the pipe

Weight per meter, w (kg/m)	Thickness (mm)	Elastic modulus, E (MPa)	Poisson's ratio, ν	Pipe diameter (mm)	Pipe material
4.83	0.4	1000	0.3	250	polyethylene

4. Test setup and test preparation

Laboratory tests were performed using a physical, three-dimensional large-scale model that would be expected to behave similar to full-scale in the field. The trenches, with desired dimensions, were built in a rigid box with dimensions of 2200 mm×2200 mm×1000 mm and refilled by backfill soil as shown in Figure 2. Loading system consists of a hydraulic cylinder which can produce static and cyclic loading up to 100 kN. Data acquisition system controls the whole system within internal processor which records all the output data streams from load cell, pressure cells and LVDTs. The trench contains the geocell reinforced soil and

model pipe testing was prepared in the testing tank. The pipe's crown displacement was measured by one LVDT which installed inside the pipe, exactly under the centre of loading plate. To investigate the transferred pressure to the pipe, two pressure cells having diameter of 50 mm were installed on the crown and wall of the pipes.

Based on ASTM D2321-08 recommendation, the width of the trench should be at least equal to $W=1.25D+300$. According to AASHTO (2010), the minimum width of the trench should be greater than the values represented in Eqs. (1) and (2).

$$W = 1.5D + 305 \quad (1)$$

$$W = D + 406 \quad (2)$$

W and D are respectively the minimum trench width and pipe diameter (in mm). Thus, to satisfy the minimum width defined by the Standards, for the pipe diameter of 250 mm, the trench width of 750 mm and length of 1500 mm is selected. The trench height varies depending on the embedment depth of the buried pipe (1.5D and 2D). Figure 2 shows the schematic view of the experimental model setup including hydraulic jack, geocell layer, buried pipe, instrumentation and parameters used in the experiments.

The backfill soil at an optimum moisture content of 5.7% and maximum dry density of 20.62 kN/m³ was compacted in six layers around and over the pipe by the vibrating compactor. When the soil surface reached to the required level, a rigid loading plate with a diameter of 250 mm and thickness of 25 mm was placed over the center of trench while the load cell and LVDT (to measure the applied load on the loading plate and its settlement) were installed. In all the tests and to simulate the vehicle loading, 150 cycles of repeated loading with amplitude of 800 kPa and frequency of 0.33 Hz was applied on the loading plate. Figure 3 also depicts two photographs of the test installations (geocell installation beneath the loading plate and circular loading plate just prior to loading).

5. Testing Program

The details of all the test series done in this study are given in Table 3. The width of the geocell layers (b) and the depth to top of the first geocell layer below the footing (u) are 5D (125 mm) and 0.2D (50 mm) [21] which D is the loading plate diameter (D=250mm) (see Fig. 2). As seen in Table 3, two different geocell's pocket sizes with height of 100 mm were used in the geocell reinforced installations.

Table 3. Testing programme and parameters

Type of test	Opening Dimensions (mm)	Buried depth of pipe	Test No.
Unreinforced	-----	2D (Shallow)	1
		1.5D (Shallow)	2
Geocell reinforced (H=100 mm)	110×110	2D (Deep)	3
	110×110	1.5D (Shallow)	4
	55×55	2D (Deep)	5

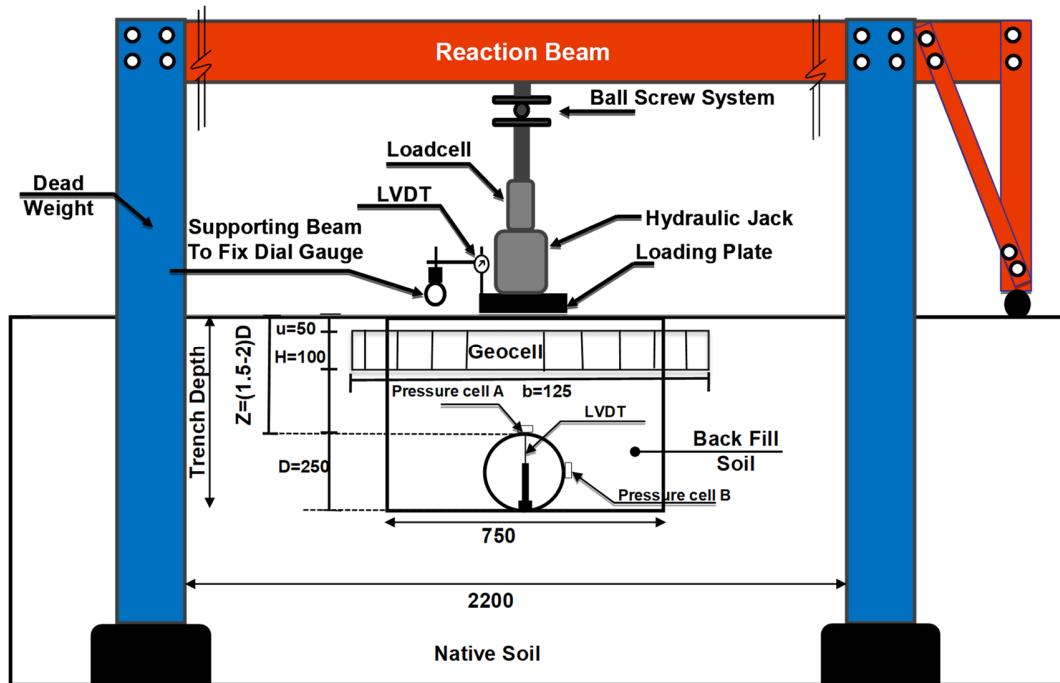


Figure 2. Schematic view of test setup, position of instrumentation and geometric parameters (unit in mm)



(a)



(b)

Figure 3. Test installation (a) geocell installation beneath the loading plate, (b) load plate (circular) just prior to loading

6. Result and Discussions

In this section, the results of the tests are presented along with a discussion highlighting the effects of the geocell layer and embedment depth of pipe on the variations of pipe deformation, soil surface settlement and transferred pressure to the pipe's crown.

6.1. Pipe deformation

Figure 4 depicts the VDS variations versus time for unreinforced and reinforced installations shown in Table 3. The pipe was placed in shallow depth ($1.5D = 375$ mm) and deep depth ($2D = 500$ mm). As shown in this figure, for the pipe with embedment depth of $1.5D$ (shallow depth) in unreinforced trench unstable condition was happened. Plus, this figure illustrates that with increase the embedment depth of pipe to $2D$ (deep depth) and the trench reinforced by geocell layer, VDS value reduces dramatically and the stable conditions were happened. According to Figure 4, for two different aperture sizes of geocell ($55 \times 55 \times 100$ and $110 \times 110 \times 100$ mm) it is seen that the pipe displacement for geocell with larger aperture size is greater than that of with smaller size. This behaviour can be attributed to geocell aperture size and their behaviour under loading, in a way that the smaller aperture size of geocell gives the greater resistance against stretching when loaded. Overall, the VDS reduction is that because of using geocell as distributed stress on pipe surface decreases for membranous function of geocell layer.

6.2. Soil Surface settlement

Figure 5 indicates the variation of soil surface settlement (SSS) with time for different installations. According to the figure, if the embedment depth grows from $1.5D$ to $2D$, the SSS value becomes smaller. As an example at the end of loading which is cycle of 150 when the geocell with 110×110 aperture size is used as reinforcement layer. In this case, the SSS value is 60 mm for embedment depth of $1.5D$ due to adjacency of trench surface to pipe crown. This considerable SSS reduced about 50% with increase in the embedment depth from $1.5D$ to $2D$. These results are in line with findings of other researchers [11, 16, 22].

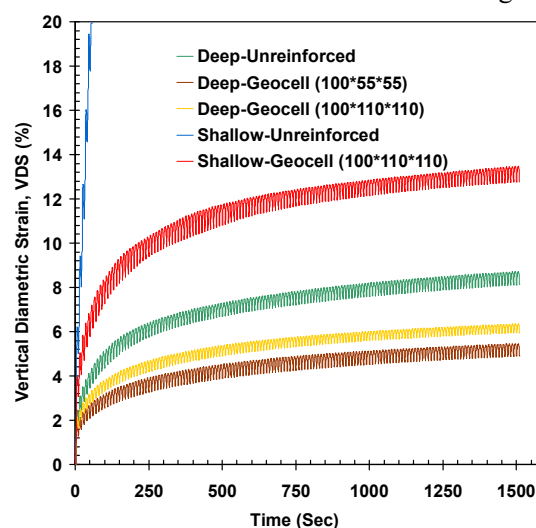


Figure 4. Variations of VDS versus time for unreinforced and geocell reinforced installations

Comparing the SSS value for two aperture size of 55×55 and 110×110 and embedment depth of 2D (deep installation) in Figure 5, depicts that an increase in the in the aperture size does not lead to alteration in surface settlement. As an illustration, for unreinforced system and reinforced system by geocell with aperture size of 55×55 and $110 \times 110 \text{ mm}^2$, SSS at the last cycle of loading is equal to 53.2, 29.8 and 28.4 mm, respectively. This comparison shows that, the geocell reinforced trench with aperture size of 55×55 results in settlement decrease by merely 5% when compared with that of $110 \times 110 \text{ mm}^2$, but results in 46% decrease compared to unreinforced soil bed. The upshot of this section shows how influential geocell and embedment depth of pipe is to diminish surface settlement even if the stress amount applied to trench surface is large enough.

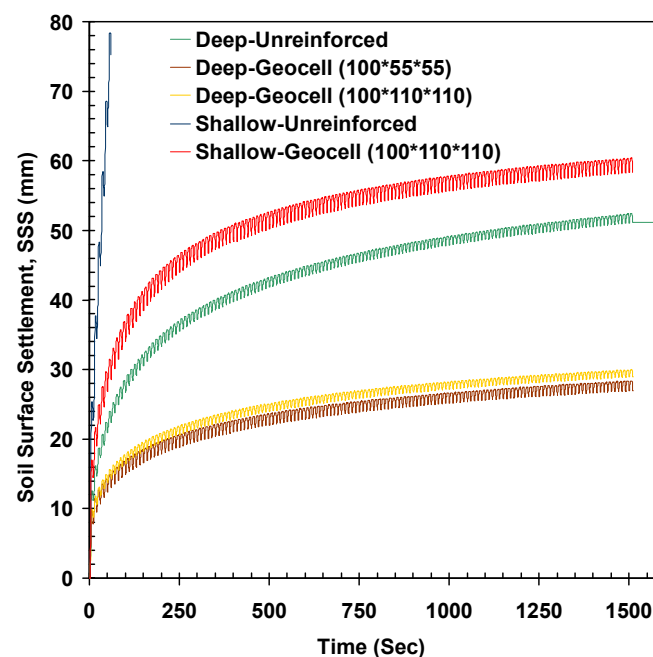


Figure 5. Variations of SSS versus time for unreinforced and geocell reinforced installations

6.3. Transferred Pressure to pipe

In order to investigate the influence of geocell reinforcement on the stress reduction on the pipe, the variation of pressure with number of load cycle for the crown and springline of the pipe are shown in Figure 6. According to this figure, transferred pressure on the pipe's crown is the largest when soil is unreinforced and the least when it is reinforced by geocell with smaller aperture size. For example, at 10th load cycle, the pressure value on the crown and springline of pipe have been dwindled with geocell reinforcement, by 32 and 16 % respectively, compared to the trench with no reinforcement. In addition, for unreinforced soil system, maximum pressure is created up to cycle 25 declining after wards due to soil failure. The stress reduction in presence of geocell layer could be attributed to interaction between soil and geocell when combined. This function on one hand does not let the soil element moves laterally when subjected to loads, and on the other hand causes stress to distribute widely on the surface. This matter also creates false cohesion in backfills where with increasing number of geocell apertures, the confinement and false cohesion grows notably as well. In fact, geocell acts as a rigid slab with high rigidity leading to stress distribution expansively in depth of the trench.

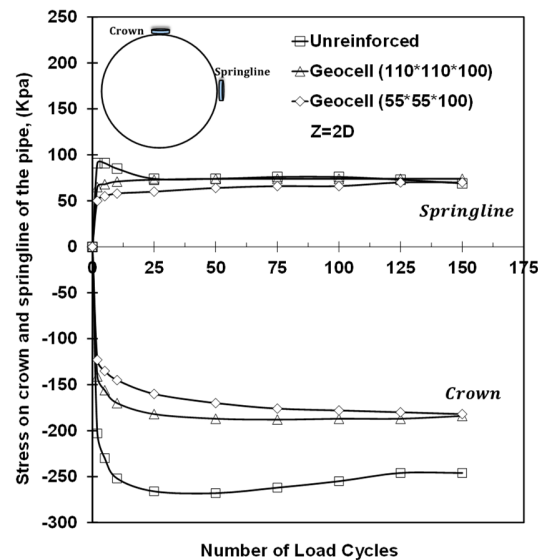


Figure 6. variation of transferred pressure to pipe for unreinforced and reinforces installations

7. Conclusions

In this study, a series of full-scale tests was designed to investigate the performance of pipes buried in unreinforced trench and geocell reinforced trench, subjected to repeated loading. The results could be summarized as follow:

- The geocell application led to attenuation VDS, SSS and transferred pressure to the pipe.
- With increase in the embedment depth of pipe, VDS and SSS values is significantly lessened.
- Pipe crown displacement when geocell with 55×55 aperture size is used shrinks by 14% in comparison with geocell with 110×110×100 aperture size.
- As an illustration, the aperture size of geocell has no significant effect on SSS value. For example, for the geocell reinforcement with aperture size of 55×55 and 110×110 mm², SSS value at the last cycle of loading is equal to 29.97 and 28.34 mm.
- The acting pressure on pipe's crown is the largest when soil is unreinforced and the least when it is reinforced by geocell with smaller aperture size. For example, the pressure value on the crown of pipe for the reinforced trench reduced by 32% as compared with the unreinforced trench.

Acknowledgment

This paper includes results created within the project SGS-2015-028 "Semi-solid Processing and New Structures without Carbide Net" subsidized from specific resources of the state budget for research.

References

- [1] A. Marston, and A. O. Anderson, "The theory of loads on pipes in ditches and tests of cement and clay drain tile and sewer pipe", Bull. 31, Iowa Engineering Experiment Station, Ames, Iowa, 1913.
- [2] M. G. Spangler, "The structural design of flexible pipe culverts," Bull.31, Iowa Engrg. Experiment Station, Iowa State College, Ames, Iowa, 1941.

- [3] J. J. Trott, and J. Gaunt, "Experimental performance of pipelines under a major road: performance during and after road construction," Lab. Rep.692, Transport and Road Research Laboratory, Crowthorne, Berkshire, U.K, 1976.
- [4] M. Arockiasamy, O. Chaallal, and T. Limpeteeparakarn, "Full-scale field tests on flexible pipes under live load application," Journal of performance of constructed facilities, ASCE 20(1), pp. 21-27, 2006.
- [5] M. L. Talesnick, H. W. Xia, and I. D. Moore, "Earth pressure measurements on buried HDPE pipe," Géotechnique 61(9), pp. 721–732, 2011.
- [6] M. R. Ahmed, M. A. Meguid, J. Whalen, "Laboratory Measurement of the Load Reduction on Buried Structures overlain by EPS Geofoam," 66th Can. Geotech. Conf., Montreal, CD, 8 pages, 2013.
- [7] Khalaj, O., Moghaddas Tafreshi, S.N., Mask, B., and Dawson, A.R., (2015). Improvement of pavement foundation response with multi-layers of geocell reinforcement: Cyclic plate load test, Geomechanics and Engineering, 9 (3), 373-395
- [8] Moghaddas Tafreshi, S.N., Khalaj, O. and Dawson, A.R., (2014). Repeated loading of soil containing granulated rubber and multiple geocell layers, Geotextiles and Geomembranes, 42, 25-38
- [9] Moghaddas, Tafreshi, S.N., Khalaj, O. and Dawson, A.R., (2013). Pilot-scale load tests of a combined multilayered geocell and rubber-reinforced foundation. Geosynthetics International, 20(3), 143–161.
- [10] O. Anil, R. TugrulErdem, E. Kantar, "Improving the impact behavior of pipes using geofoam layer for protection," International Journal of Pressure Vessels and Piping 131-132, pp. 52-64, 2015.
- [11] A. M. Hegde, O. Sitharam, "Experimental and numerical studies on protection of buried pipelines and underground utilities using geocells. Journal of Geotextiles and Geomembranes 43, pp. 372-381, 2015.
- [12] N. R. Krishnaswamy, K. Rajagopal and G. MadhaviLatha, "Model studies on geocell supported embankments constructed over a soft clay foundation," Geotechnical Testing Journal, 23(1), pp. 45-54, 2003.
- [13] S. K. Dash, S. Sireesh, and T. G. Sitharam, "Behaviour of geocell-reinforced sand beds under circular footing," Ground Improvement 7(3), pp. 111–115, 2003.
- [14] T. G. Sitharam, and S. Sireesh, "Behaviour of embedded footings supported on geocell reinforced foundation beds," Geotechnical Testing Journal, ASTM 28, 452–463, 2005.
- [15] S. K. Dash, P. D. T. Reddy, and S. T. G. Raghukanth, "Subgrade modulus of geocell-reinforced sand foundations," Ground Improvement 161, pp. 79–87, 2008.
- [16] G. Sitharam G., Sireesh, S. T. and Dash, S. K, "Performance of surface footing on geocell-reinforced soft clay beds," GeotechGeolEng. 25, pp. 509–524, 2007.
- [17] S. N. Moghaddas Tafreshi, and A. R. Dawson, "Behaviour of footings on reinforced sand subjected to repeated loading – Comparing use of 3D and planar geotextile," Geotextiles and Geomembranes28(5), pp. 434–447, 2010b.
- [18] S. N. Moghaddas Tafreshi, P. Sharifi, A. R. Dawson, "Performance of circular footings on sand by use of multiple-geocell or -planar geotextile reinforcing layers," Soils and Foundations 56 (6), pp. 984-997, 2016.
- [19] S. N. Moghaddas Tafreshi, and O. Khalaj, "Laboratory tests of small-diameter HDPE pipes buried in reinforced sand under repeated-load," Journal of Geotextiles and Geomembranes 26(2), pp. 145-163, 2008.
- [20] S. N. Moghaddas Tafreshi, Gh. Tavakoli Mehrjardi, "The use of neural network to predict the behavior of small plastic pipes embedded in reinforced sand and surface settlement under repeated load, "Engineering Applications of Artificial Intelligence21(6), pp. 883-894, 2008.

- [21] S. N. Moghaddas Tafreshi, A. R. Dawson, A comparison of static and cyclic loading responses of foundations on geocell-reinforced sand. *Geotext. Geomembr.* 32(5), pp. 55-68, 2012.
- [22] Gh, Tavakoli Mehrjardi, S. N. Moghaddas Tafreshi, A. R. Dawson, "Pipe response in a geocell-reinforced trench and compaction considerations," *Geosynth. Int.* 20 (2), pp. 105-118, 2013.
- [23] American Society for Testing and Materials (ASTM). Standard practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). ASTM, D 2487, 2011.
- [24] American Society for Testing and Materials (ASTM). Standard practice for underground installation of thermoplastic pipe for sewers and other gravity-flow applications. ASTM, D 2321-08, 2008.