Effect of geofoam location and density on the improvement of buried flexible pipe

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ABSTRACT: In this study, the effects of geofoam location and density for buried pipelines is investigated in laboratory physical model tests. Experiments are conducted in a box having 1 m x 1 m area and 0.6 m height, where a clean sand is used as the bedding and surrounding material. A 20-cm-diameter PVC pipe is positioned on a 10-cm-thick bedding soil layer, and above the pipe EPS geofoam plates with two different densities are placed with varying distances from the pipe crown (0, 5 and 10 cm above the crown). Incremental static loading is applied to the ground surface via a circular steel plate (such as in a plate load test) and vertical deformation of the pipe, as well as that of the ground surface, are measured. Geofoam creates a compressible zone over the pipe, which initiates soil arching and transfers the load above the pipe to surrounding soil. It is seen that introduction of geofoam improves the pipe deformation behavior provided that geofoam does not yield. Moreover, it is observed that better improvement is achieved when geofoams are placed closer to the pipe crown. When different density EPS plates are considered, lighter density EPS acts as better compressible inclusion, hence shows better improvement on pipe for lighter surface loads. However, it is seen that denser geofoam shows improvement for a wide range of applied stress compared to EPS with lower density.

Keywords: EPS geofoam, buried pipe, compressible inclusion, improvement

1 INTRODUCTION

Buried pipelines have become one of the most common, economical and safe means of conveying fluids (water, gas, petroleum etc.) from a region to another, ranging from a few meters to thousands of kilometers. Some of the loads considered in buried pipe design are: internal pressure, vertical earth loads, surface live loads, surface impact loads, buoyancy, thermal expansion, relative pipe-soil displacement, movement of pipe bends, subsidence, earthquake etc. The pipes could be damaged during their service life under the applied load conditions. In order to reduce the load over the pipe, the imperfect trench method can be applied. Marston (1930) developed this method which depends on creating a compressible region over the pipe. This compressible inclusion induces arching due to relative settlement, hence a portion of the soil's self-weight is transferred to the adjacent side soils by frictional forces; as a result, the vertical earth load on the conduit becomes less than the self-weight of the overlying soil prism (Kang, 2007) (Figure 1). Leaves (Spangler 1958), baled straw (Larson 1962), tire-soil mixtures (Jean & Long, 1990), cardboards (Edgar et al., 1991), sawdust (McAffee and Valsangkar 2004), woodchips (McQueen, 2000; McAffee and Valsangkar 2004) have been used as compressible materials with buried pipelines. Compressible inclusions are obtained with these materials, however, in general, it is hard to predict and control their stress-strain behavior. Moreover, some of these materials are biodegradable and decomposition of these materials will create a large void and it will lead to surface depression (Horvath, 1997). Recently, geofoam has been preferred as compressible inclusion because it does not suffer from these drawbacks (e.g. Kilic and Akinay 2017).

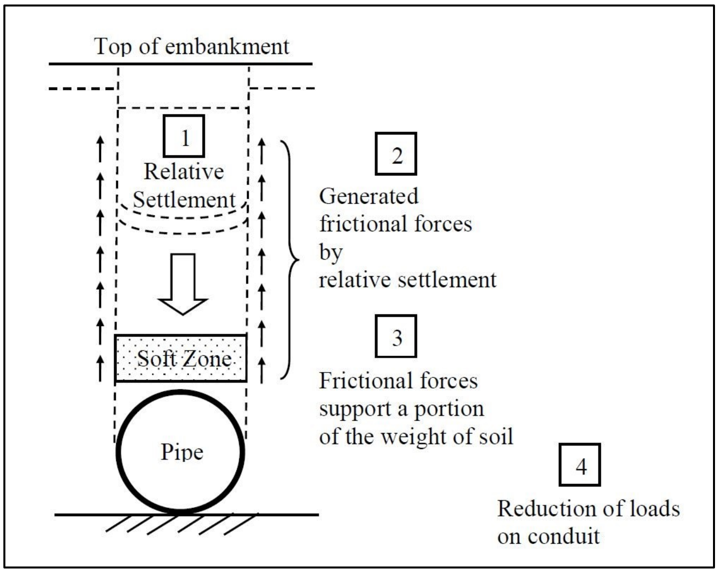


Figure 1. Induced forces and arching mechanism in buried pipelines (Kang, 2007)

1.1 *Background*

Vaslestad et. al (1993) is one of the pioneer studies related with geofoam application under high embankments over rigid pipes. Geofoam inclusion reduced the stress on the pipes to 25% of the calculated overburden pressure whereas no-geofoam case resulted in 24% stress increase on calculated pipe stress. Rigid pipes are likely to be subjected to negative arching under embankments therefore geofoam inclusion may change this situation into positive arching. Oshati et al. (2012) compared the earth pressures on a double-cell rectangular box culvert constructed by induced trench method under a 25-m-high embankment. Measured vertical load on top of the culvert was only 42% of the calculated overburden pressure. Kilic and Akinay (2017) conducted laboratory tests in a 1.5 m x 1.5 m x 1.5 m box, for 30-cm diameter HDPE pipe where the pipe was wrapped with EPS geofoam with 10 kg/m^3 nominal density. Vertical pressure, up to 200 kPa, was applied to ground surface through a rigid plate. 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 where geofoam was not used. The maximum absolute value of vertical and horizontal deflections of the pipe (in terms of the pipe diameter) were measured as 0.40% and 0.65%, respectively. These values were 87% and 60% less, respectively, than those measured at the reference test in which no EPS geofoam was used.

Numerical analyses have been done to determine the optimum geofoam geometry for buried pipes. Kim and Yoo (2005) figured out that no more significant improvement is observed if the geofoam width or height is more than 1.5 times pipe diameter. Kim et al. (2010) showed that double geofoam layer application does not reduce vertical load on pipe significantly compared to single geofoam case. There are other studies about optimum geofoam geometry determination by applying numerical analyses (Sun et. al, 2005; McGuigan and Valsangkar, 2010; Withoeft and Kim, 2016).

Improvement effect of geofoam application and determination of optimum geofoam geometry are also studied by centrifuge tests. Okobayashi et al. (1994) visualized arching effect on the culvert and oberved the geofoams' contribution to stress reduction of vertical earth pressure. McGuigan and Valsangkar (2010) demonstrated that geofoam application reduced the anticipated vertical load by 75%. Centrifuge tests were also made to observe the effects of construction methods, the spacing of box culverts and compressible zone geometry on double trench box culverts (Bourque, 2002; McAffe, 2005; McGuigan and Valsangkar, 2010).

After an extensive literature review, it is seen that flexible (PVC) pipes with and without geofoam under a static loading, and the effect of geofoam density or location in lab scale experiments were not studied. Also, shallowly buried pipes are not studied with geofoam applications; literature search showed that pipes were buried very deep in terms of burial depth to diameter ratio. Based on these factors, it is seen necessary to study the effects of geofoam density and location on improvement of buried flexible PVC pipe via lab model tests.

2 TEST MATERIALS AND EQUIPMENT

2.1 *Soil properties*

In this study, Cine sand is used as bedding material and backfill soil in the laboratory model experiments. Cine sand is classified as a poorly-graded sand, SP, referring to the Unified Soil Classification System (ASTM D2487). Index properties of Cine sand can be seen in Table 1. In the model tests, sand is prepared at a void ratio of less than or equal to 0.540 to achieve a relative density of 85% or more, which is stated in the guidelines of State Hydraulic Works of Turkey. Relative density of the backfill soil is checked by small density boxes in experiments.

Table 1. Properties of the soil used in this study

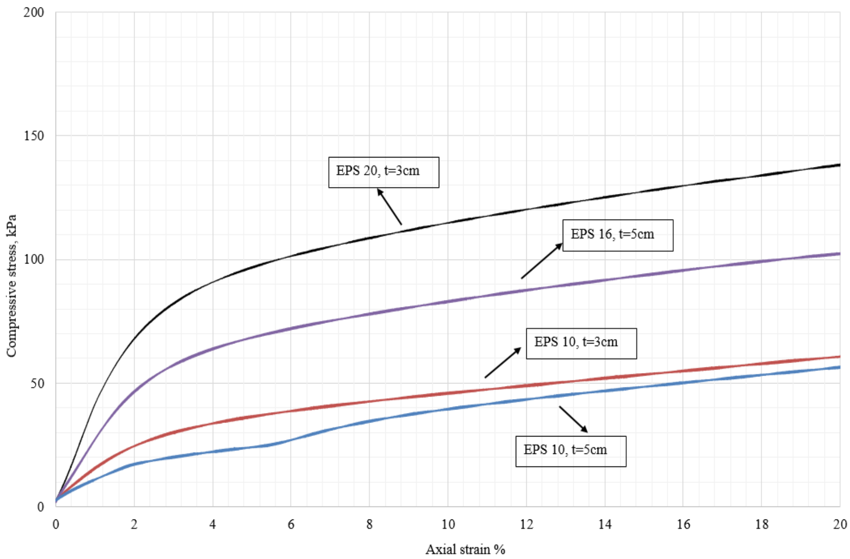
Soil property and its unit	Value
D_{10}, mm	0.135
D_{30}, mm	0.255
D_{60}, mm	0.47
Coefficient of curvature, C_c	1.02
Coefficient of uniformity, C_u	3.48
Fines content, % (% ≤ 0.074 mm)	1.35
Specific Gravity	2.66
Max. void ratio (e_{max})	0.825
Min. void ratio (e_{min})	0.505
Void ratio achieved in model lab tests (e)	≤ 0.540

2.2 *PVC pipe*

In the experiments, PVC pipe with 200 mm outer diameter, and 3.9 mm wall thickness, and length of 90 cm is used. This pipe is mainly used for underground drinking water and wastewater networks in Turkey. Parallel plate load test is conducted (ASTM D-2412) and pipe stiffness is calculated as 1.68 MPa.

2.3 *EPS geofoam*

In experiments, identical geofoam plates are used. All geofoam plates have 90 cm length and 20 cm width. In order to study the effects of the location of geofoam relative to pipe crown, EPS with density of 14.3 kg/m^3, and 4-cm-thick plates are used. Effect of EPS density on pipe improvement is studied by using 2-cm-thick plates with 16.3 and 28 kg/m^3 densities. EPS properties are dependent on its dimensions and density. Therefore stress-strain graphs for EPS plates with varying thickness and density values are obtained in the Materials Testing Laboratory of Middle East Technical University by applying a rate of 10% strain per minute as stated in ASTM D6817 (Figure 2). Based on these tests, corresponding stress values for any strain amount of different EPS plates are plotted.



(a) (b)

Figure 2. (a) Compression tests on EPS geofoam plates, (b) Stress-strain graphs of EPS plates

2.4 *Test box*

Test box is composed of laminar segments whose height is 10 cm and area is 1 m x 1 m (Figure 3). In the experiments, tank is filled to a height of 60 cm, segments are taped inside and outside to prevent flow of soil. After the soil sample is prepared in the box, static loading is applied on the surface of the sand via a 26-cm-diameter steel plate and a load cell is connected to the pneumatic loading. There are 2 dial gages on the plate to read the surface settlement and to check if there is any eccentricity/tilting of the loading plate.

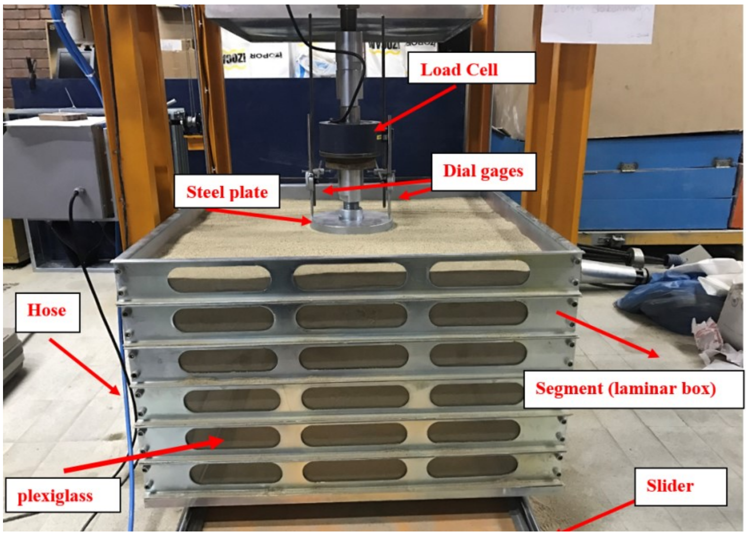
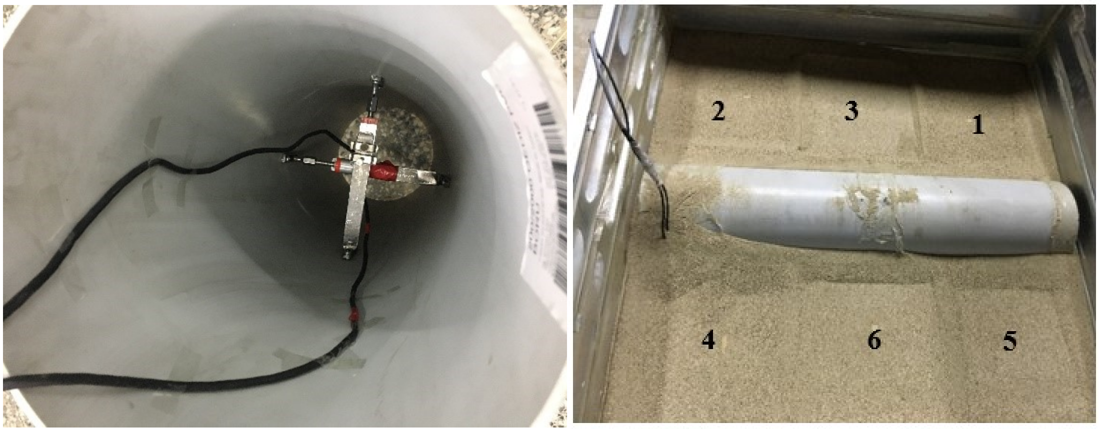


Figure 3. Test box components

3 TEST PREPARATION

Two potentiometers are placed inside the pipe to measure vertical and horizontal deformations of the pipe (Figure 4a). In the tests, PVC pipe is always placed on a 10-cm-thick bedding layer. Relative density of the bedding and backfill soil is required to be at least 85% according to guidelines of Turkish State Hydraulics Works, therefore a vibratory plate is used to achieve this density. By using a 30 cm x 30 cm wooden plate in between soil layer and vibratory plate, soil is compactd in 6 or 9 zones, depending on the pipe existence or not in the region (Figure 4b). Figure 4b shows 6 zones of compaction around the pipe. Sand is compacted as homogeneously as possible in layers of 10 cm height. In trial tests, small containers are placed in each 10-cm-thick soil layer, at different locations of the box, to check the uniformity of soil placement and the achieved density (Soylemez, 2017).



(a) (b)

Figure 4 (a) Potentiometers installed inside the pipe, (b) Compaction of soil in six zones around pipe

Sand is placed and compacted up to the level where the pipe is to be placed, then pipe is placed and compaction is continued around the pipe (Figure 4b) until soil level reaches to the level where geofoam is to be placed. Prior to geofoam placement, soil surface is leveled. Then the geofoam plate is placed and tank is filled to get a total of 60-cm height of compacted sand. Then, 26-cm diameter steel plate is placed on the ground surface at the center point of the box. Two dial gages are placed on the steel plate to record plate settlements. Progressively load is increased and settlement of the plate is recorded until a stable reading is obtained; and loading is continued until geofoam yields and pipe deformations increase. Load applied on the plate, settlement of the plate and vertical deformation of the pipe is recorded throughout the experiment.

4 EXPERIMENTS AND RESULTS

In this study, total of 6 experiments are presented. As the reference experiment, the pipe is placed in the box without any geofoam plate above it. In other experiments, effect of the geofoam placement location and density of geofoam on the pipe deformation improvement is investigated.

4.1 *Effect of geofoam location on the deformation of the pipe*

EPS 14.3 kg/m^3, having 20 cm width, 4 cm thickness and 90 cm length is placed above the pipe in 3 different configurations having 0, 5 and 10 cm vertical distance from the pipe crown (Figure 5).

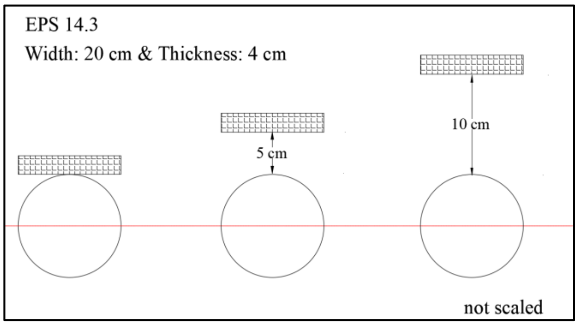


Figure 5. Geofoam locations above the pipe crown

Stress at the steel plate and pipe vertical deformation (as a percentage of pipe internal diameter) is plotted in Figure 6. It is seen in Figure 6 that, for the stress range of 0-400 kPa, with geofoam application, for the same amount of pipe deformation, pipe endures higher loads compared to without geofoam case, for the sress range up to the yield stress of geofoam. Test results show that as geofoam is placed closer to the pipe crown, better improvement is observed. Figure 6 shows that geofoam placed just above the pipe (0 cm vertical distance) shows improvement up to 400 kPa whereas geofoam placed 10 cm above the pipe shows improvement only up to 200 kPa applied stress. Geofoam that is placed 10 cm above the pipe makes insignificant improvement on the pipe deformation. However, vertical deformation of the pipe decreases nearly 50% when geofoam is placed on the crown or 5 cm above the pipe. Vertical stresses above the geofoam is calculated by 2V:1H approach and corresponding geofoam strains are calculated. It is noted that geofoams yielded at 10% to 18% vertical strain (calculated in terms of geofoam plate thickness) and if geofoam is located closer to pipe, it endured higher strain amount. In the lights of above findings, it can be said that pipe has better improvement if the geofoam is located closer to pipe crown, provided that it will not be subjected to higher loads than the yield stress of geofoam.

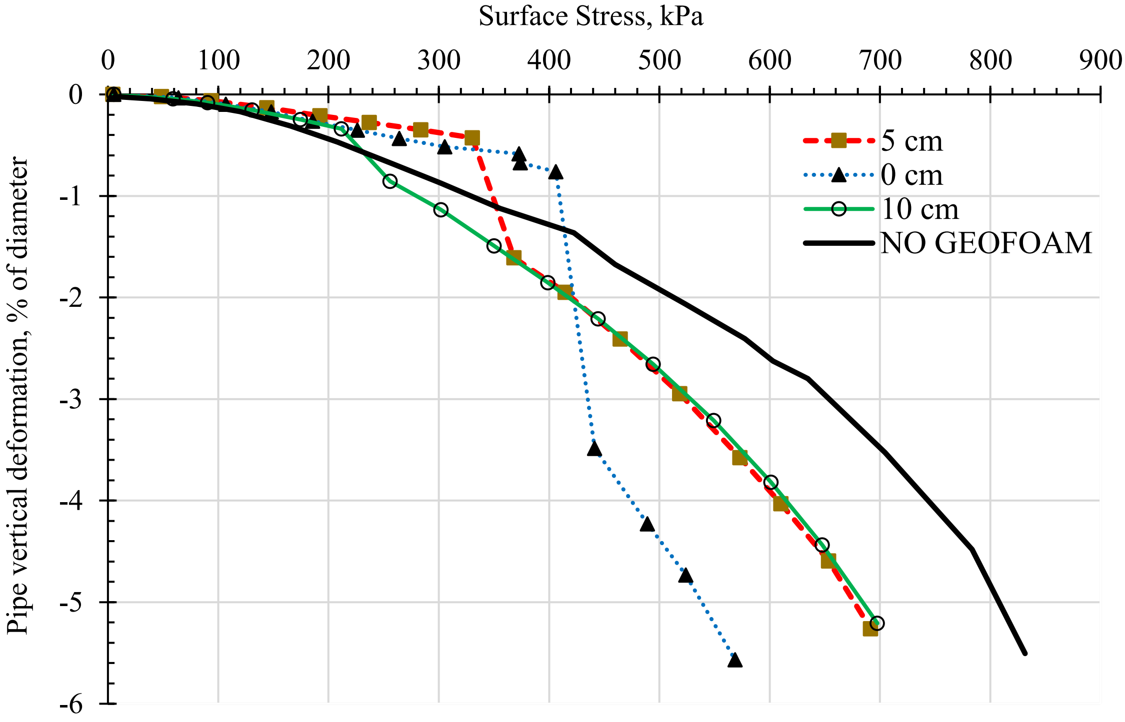


Figure 6. Test results for effect of geofoam location on pipe vertical deformation (negative sign in vertical axis indicates compression of the pipe)

However once the geofoam is overloaded (yields), it crushes and a sudden settlement occurs on the ground surface, and pipe experiences significant vertical compression. The reason behind this fact is that, surface load starts to be applied closer to pipe as can be seen in Figure 7. This situation makes the system even worse compared to no geofoam case. Therefore it has paramount importance to be aware of geofoam yield load. In buried pipeline design, allowable vertical pipe deformations can be in the range of 5% to 7.5% of pipe internal diameter according to guidelines used in different countries. However, in the case of geofoam usage above the pipe, before the pipe experiences vertical deformation of 5% pipe diameter, geofoam may collapse and therefore allowable deformations in the design should be considered carefully.

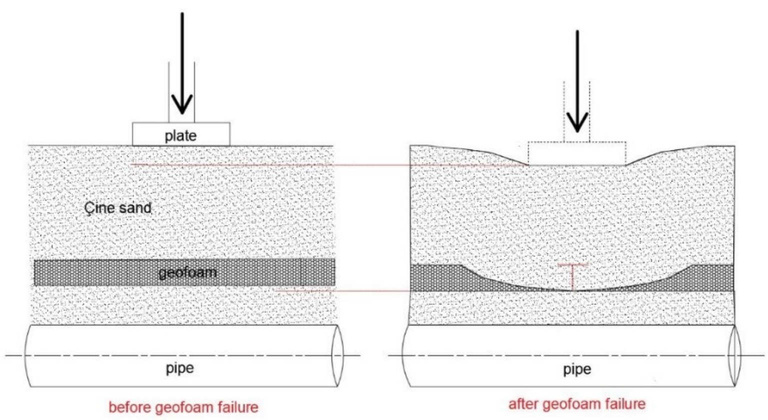


Figure 7. Loading configuration and vertical deformation of geofoam after geofoam is overloaded

4.2 *Effect of geofoam density on the deformation of the pipe*

Positive soil arching over the pipe affects the pipe vertical deformation significantly. Mobilization of the soil arching depends on compressible zone properties. Therefore two different EPS geofoam density is used in the experiments, namely EPS 28 and EPS 16.3, where the numbers refer to the density of geofoams in units of kg/m^3. Test results can be seen in Figure 8. Application of both EPS density panels showed improvement up to yield stresses of geofoams, however lighter density (more compressible) geofoam showed better improvement on the pipe deformation, for the same applied surface stress range up to 300 kPa, compared to denser EPS. Denser EPS showed improvement over a larger stress range (up to 550 kPa). Denser geofoams will have higher stiffness, which means higher loads are required to deform them. Soil arching is mobilized due to the deformation of the EPS, therefore it is vital to anticipate the deformation amount of the EPS under the applied load. Load level has siginificant effect to choose the suitable EPS density to be placed over the pipe.

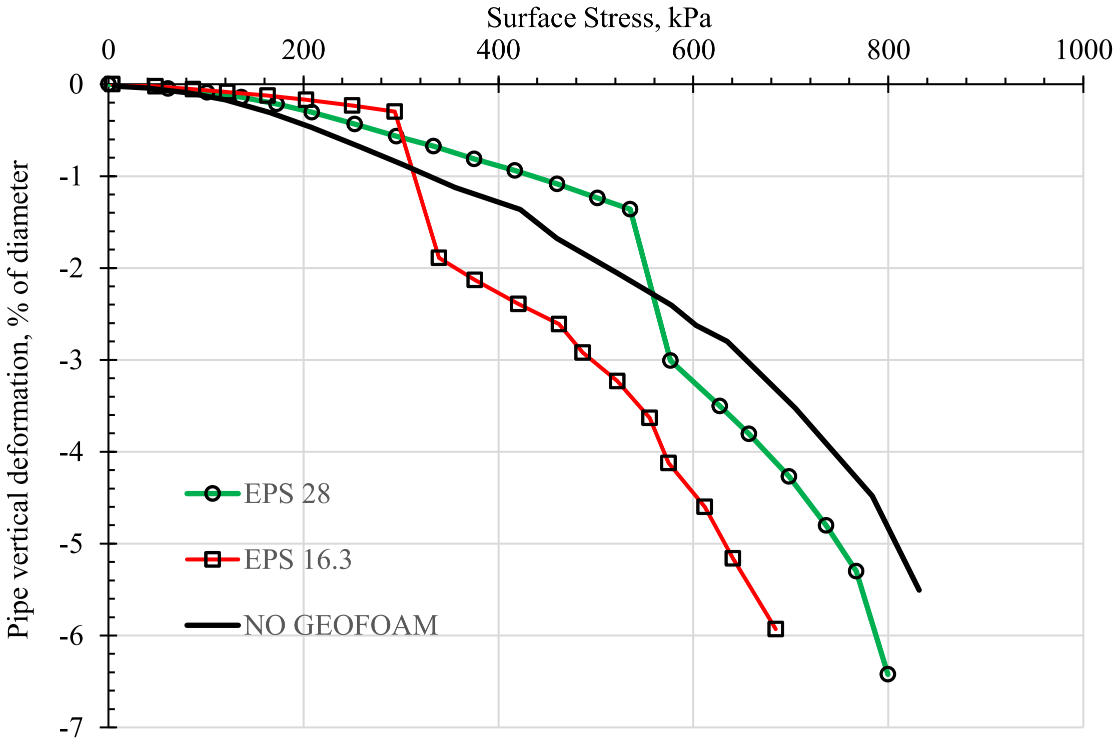


Figure 8. Test results for effect of geofoam density on pipe vertical deformation (negative sign in vertical axis indicates compression of the pipe)

5 SUMMARY AND CONCLUSIONS

In this study, the effects of EPS geofoam location and density are studied to compare the improvement on the vertical deformation of the buried flexible pipe. Tests are conducted on PVC pipe with 20 cm diameter. Static incremental load is applied through a 26-cm-diameter steel plate on the ground surface and the following results are obtained:

1. In terms of location criteria, as the geofoam is placed closer to the pipe crown, improvements on pipe vertical deformation have been observed for a larger range of surface stress.
2. Considering vertical location of the pipe relative to pipe crown, 5 cm and 10 cm EPS placement experiments showed identical behavior after failure. It means that once yield stress is exceeded, EPS location becomes unimportant.
3. Density criteria tests showed that, a lighter EPS acts as a better compressible inclusion compared to the denser one. For the initial loadings it is seen that, with lighter EPS, pipe had less vertical deformation.
4. Denser EPS has higher stiffness, and hence, it is less likely to deform under small stresses compared to lighter EPS. In dense EPS applications, little positive arching will be observed for smaller surface

stresses. However, denser geofoams improved the pipe deformation for a higher stress range due to its higher stiffness compared to lighter geofoams.

Above findings are valid for stated scenarios. More experiments should be done for other flexible (or rigid) pipes with different soil density and/or soil type. It will be also very good to have the horizontal deformation readings and obtain the deformed pipe geometry for every stage.

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